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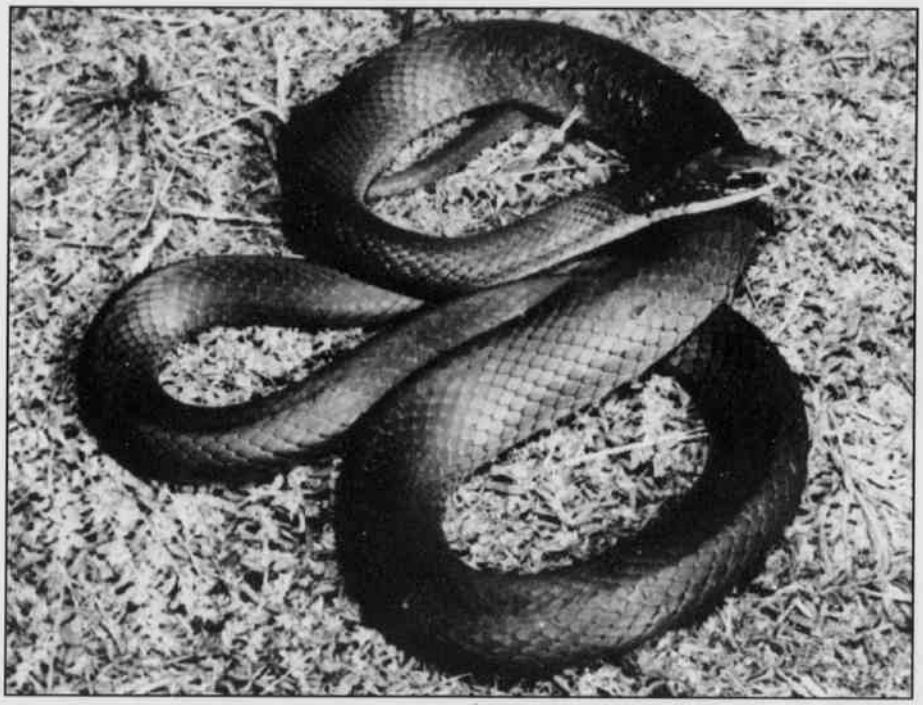

ARKANSAS ACADEMY OF SCIENCE
DEPT. OF NATURAL SCIENCE
MONTICELLO, ARKANSAS 71655

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Dwight M. Moore, 1932-33, 64
Flora Haas, 1934
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L. B. Ham, 1936
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M. J. McHenry, 1938
T. L. Smith, 1939
P. G. Horton, 1940
I. A. Willis, 1941-42
L. B. Roberts, 1943-44
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H. L. Winburn, 1946-47
E. A. Provine, 1948
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Arthur Fry, 1969
M. L. Lawson, 1970
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Clark McCarty, 1974
Edward Dale, 1975
Joe Guenter, 1976
Jewel Moore, 1977
Joe Nix, 1978
P. Max Johnston, 1979
E. Leon Richards, 1980
Henry W. Robison, 1981
John K. Beadles, 1982
Robbin C. Anderson, 1983
Paul Sharrah, 1984
William L. Evans, 1985
Gary Heidt, 1986
Edmond Bacon, 1987
Gary Tucker, 1988
David Chittenden, 1989
Richard K. Speairs, Jr. 1990
Robert Watson, 1991
Michael W. Rapp, 1992
Arthur A. Johnson, 1993
George Harp, 1994
James Peck, 1995
Peggy R. Dorris, 1996
Richard Kluender, 1997

INSTITUTIONAL MEMBERS

The Arkansas Academy of Science recognizes the support of the following institutions through their Institutional Membership in the Academy.

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MISSISSIPPI COUNTY COMMUNITY COLLEGE, Blytheville
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UNIVERSITY OF ARKANSAS AT LITTLE ROCK
UNIVERSITY OF ARKANSAS FOR MEDICAL SCIENCES, Little Rock
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UNIVERSITY OF ARKANSAS AT PINE BLUFF
UNIVERSITY OF CENTRAL ARKANSAS, Conway
UNIVERSITY OF THE OZARKS, Clarksville
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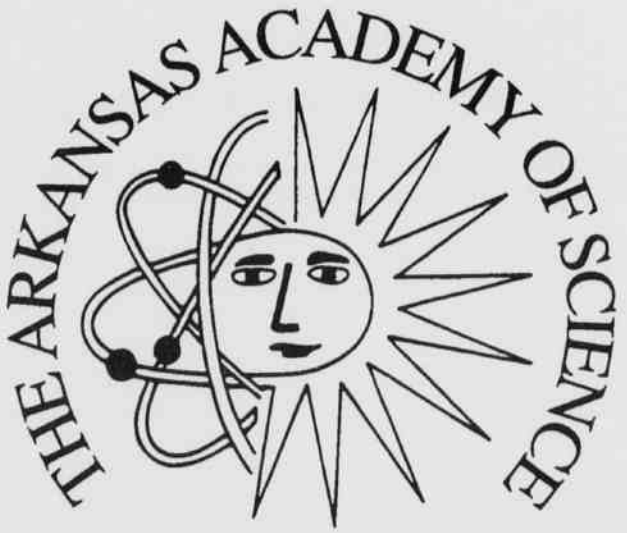
EDITORIAL STAFF

COVER: Blackmask racer (*Coluber constrictor latrunculus*) from Craighead Co., AR. Photo by Stan Trauth

Arkansas Academy of Science 1997



April 4-5, 1997
81st Annual Meeting

University of Arkansas at Monticello
Monticello

JOURNAL
ARKANSAS ACADEMY OF SCIENCE

ANNUAL MEETING 4-5 APRIL 1997
UNIVERSITY OF ARKANSAS AT MONTICELLO, MONTICELLO, AR

Secretary's Report

MINUTES OF THE 81ST MEETING

FIRST BUSINESS MEETING
4 APRIL 1997

Number present: 18
President Kluender called the meeting to order at 1105.

Kluender introduced Dr. John Annulis, Associate Vice-Chancellor for Academic Affairs, to offer the formal invitation to UAM campus. Dr. Annulis expressed appreciation for all who helped prepare the meeting and delegates for attending.

Kluender recognized the following officers for reports:

1. Local Arrangements Chair (Wiley): (1) A good banquet has been planned, and some tickets are still available. The banquet will be in the Gibson University Center at 1900 hrs. (2) If anyone has a question, the Local Arrangements Committee members can be identified by the red ribbon on their name tag. (3) The Turner Neal Museum is open; visitors are invited. (4) Encouraged students to stay for the second business meeting for the awards presentation. (5) Sigma Xi breakfast will be at 0700 Saturday at E1 Toro Restaurant. (6) A pre-banquet social hour will be at The Captain's Table at 1730 hrs; it is being sponsored by UAMS. (7) A slide preview room is set up in B-31.

2. Secretary (Rickett): (1) Membership categories report. (2) Interaction with Arkansas Environmental Federation explained (AEF has donated $600 to recognize undergraduate student papers in Environmental, Life, and Physical Sciences as 1st place ($100), 2nd place ($50) and 3rd place ($50) in each section. (3) The Secretary distributed minutes of the two 1996 general business meetings and asked for comments and/or corrections. Pending corrections, he moved (2nd: McConnell) approval of the minutes.

3. Historian (Robison.): Absent at present; no report. Came in late; this is the fourth time to meet on UAM campus.

4. Treasurer (Wiley): Distributed and reviewed an itemized financial statement of income, expenditures and endowments. Godwin moved (2nd: Daly) to accept the treasurer's report.

FUNDS

Beginning Balance - 1 January 1996		**$18,397.81**
Total Income (Page 2)	21,807.95	
Total Expenses (Page 3)	19,692.81	
Balance for the Year	2,115.14	2,115.14
CLOSING BALANCE - 31 DECEMBER 1996		**$20,512.95**

DISTRIBUTION OF ACCOUNTS

Interest Bearing Checking Account (Union Bank and Trust Co., Monticello, AR)	5,968.05
Certificates of Deposit	
Dwight Moore Endowment (Heartland Community Bank - Monticello, AR - No. 506698.1 - 5.20% Int.)	3,075.00
Life Membership Endowment (Heartland Community Bank - Monticello, AR - No. 510783.0 - 5.25% Int.)	11,469.90
TOTAL	**$20,512.95**

Respectfully Submitted,

R. Wiley

Robert W. Wiley, AAS Treasurer

Financial Statement, Arkansas Academy of Science

INCOME: 1 January 1996 to 31 December 1996

Secretary's Report

1. INDIVIDUAL MEMBERSHIPS		
a. Regular	3,825.00	
b. Sustaining	230.00	
c. Life	1,350.00	
d. Associate	315.00	
	5,720.00	5,720.00
2. INSTITUTIONAL MEMBERSHIPS		2,600.00
3. PROCEEDINGS, LIBRARY SUBSCRIPTIONS		4,471.37
4. PROCEEDINGS, MISC. SALES		226.50
5. PROCEEDINGS, PAGE CHARGES		7,525.00
6. INTEREST		
a. Interest Bearing Checking Account	159.40	
b. Dwight Moore Endowment	159.22	
c. Life Membership Endowment	365.55	
	684.17	684.17
7. ENDOWMENT DONATIONS		
a. Dwight Moore Endowment	540.91	
b. AAS Endowment	40.00	
	580.91	580.91
TOTAL INCOME		**$21,807.95**

Financial Statement, Arkansas Academy of Science

EXPENSES: 1 January 1996 to 31 December 1996

1. AWARDS		
a. Conway Trophy & Awards, Plaques - Arkansas Science Talent Search (#669)	227.90	
b. Arkansas Science Fair Association (#670)	450.00	
c. Arkansas Junior Academy of Science (#671)	250.00	
d. Michael Rapp-Plaque for Judith Bean (#676)	44.10	
	972.00	972.00
2. PROCEEDINGS		
a. Phillips Litho - Unpaid Sales Tax (#663)	52.90	
b. Stan Trauth -Editorial Consultation and Travel Vol. 49 (#664)	200.00	
c. Creative Multigraphics Vol. 49 (#667)	16,689.60	
d. Joy Trauth -Editorial Consultant Vol. 50 (#673)		500.00
	17,442.50	17,442.50
3. OFFICE EXPENSES		
a. Secretaries Office - John Rickett (#672)		539.94
4. ANNUAL MEETING		
a. Richard Kluender - Plaque (#665)		66.66
5. NEWSLETTERS		
a. Henderson State University (#666)	251.65	
b. Kwik Print (#677)	299.53	
	551.18	551.18
6. DUES		
a. National Association of Academies of Science (#662)		62.50
7. MISCELLANEOUS		
a. Bateman Printing - Endowment Brochures (#675)		58.03
TOTAL EXPENSES		**$19,692.81**

5. *Proceedings* Editor (Trauth): New volume (50) is available in the lobby; asked individuals from separate campuses to take unclaimed copies back to their respective campuses to avoid mailing costs. Stan drew attention to the fewer (than in Vol. 49) pages and cost per page and moved (2nd: Bacon) that the AAS continue to support the editor's office with $500 (Editorial Asstistant) and $200 (Editor's travel).

6. *Newsletter* Editor (Saugey): Asked if we wish to reinstitute the "News from Campuses" and, if so, asked for volunteers to gather information from respective campuses. Saugey moved (2nd: Trauth) that $800 be designated for the preparation and mailing of the *Newsletter.*

7. Nominations Committee (R.L. Watson, Phoebe Harp and Tom Buchanan) (report in absentia): Nominees for Vice-President are Mostafa Hemmati (ATU) and Will Braithwaite (UALR). Joyce Hardin (Hendrix) has been nominated for Treasurer. McDaniel moved (2nd: McConnell) that the Nominations Committee's report be accepted. Kluender then asked for nominations from the floor, but none came.

8. Kluender appointed Art Johnson to chair the Auditing Committee and get one member to assist. Kluender appointed Rick McDaniel to chair the Resolutions Committee and solicit one member to help.

9. Kluender asked for the following committee reports:
   a. Biota Committee (Doug James): James absent; no report.
   b. Development Committee (Daly): Daly is developing a mechanism to identify potential donors to solicit funds to support publication of the *Proceedings.*
   c. Westinghouse Science Talent Search (Steve Runge): In his absence, Kluender read a brief report (see Appendi.. A) and a motion for continued support of $200 to obtain plaques and certificates to the winners. Motion 2nd: Bacon.
   d. Junior Science & Humanities Symposium (Tom Palko): In his absence, Kluender read a brief report (see Appendix B).
   e. State Science Fair Association (Mike Rapp): In his absence, Kluender read a report which recognized the regional fairs and their sponsors (see Appendix C). Rapp requested continued support of $450 (2nd: Trauth).
   f. Junior Academy of Science (Robert and Raynell Skinner) (report in absentia; see Appendix C): Kluender praised the Skinners for their work with the Junior Academy and moved their request of $250 (2nd: McConnell) for continued support.

10. President Kluender asked for items of old business--none came.

11. Kluender then opened the floor for new business and recognized Saugey who reported that things have changed regarding the 1998 meeting, and it would be too expensive. Daly has graciously accepted the responsibility of going back to UAMS's official bid.

12. Kluender recognized Rickett to present three motions from the *ad hoc* Constitution Committee (2nd: Daly); Motion (1): to delete the First Business Meeting; Motion (2): to rescind the practice of giving student members a copy of the *Proceedings*; and Motion (3): to reduce student membership dues to $10 [contingent upon passage of Motion (2)]. Kluender then opened the floor for discussion. Johnson pointed out that Article 7 of our constitution states that proposed amendments must be presented at "one session" and voted on during a "subsequent session" ("session" generally taken to mean a business meeting). Johnson also suggested we might do something different to attract people to this, he considers, a gathering/initial point of contact for kicking off the meeting. Considerable discussion followed containing differing opinions; Kluender asked people to talk to others at this meeting to get a sense one way or another.

13. Kluender returned to Motions (2) and (3) and explained the increaasing cost of the *Proceedings* is eroding our endowments and to offset that, the ExCom's decision to set page charges at 75% of the last year's per-page cost. No discussion followed regarding the motions.

14. Kluender recognized Trauth to move (2nd: McDaniel) that the journal's name be changed to "Journal of the Arkansas Academy of Science" to try to get away from a perception that "Proceedings..." implies lower quality.

15. Kluender asked for new business, but none came.

16. Kluender announced that contributors should submit manuscripts to section chairs. Bacon asked Kluender to urge moderators stay on time. Daly asked the Historian and Editor if we planned to prepare anything special for Volume 50. Robison said nothing was being planned, and it might be more appropriate to wait until the year 2000 and do something special.

17. Kluender then asked for a motion to adjourn; moved by Godwin (2nd: Robison). Meeting adjourned at 1208.

SECOND BUSINESS MEETING
5 APRIL 1997

Number present: 55

President Kluender called the meeting to order at 1140 and recognized the following officers in order for reports:

1. Secretary (Rickett): He has received no corrections for the minutes of the 1996 Business Meetings. Minutes approved and accepted by voice vote.

2. Nominations Committee: nominees for Vice-President are Mostafa Hemmati (ATU) and Will Braithwaite (UALR). Joyce Hardin is nominated for Treasurer. Kluender asked for nominations from the floor, but none came. Trauth moved (2nd: Robison) that nominations for Vice-President cease; passed. Robison moved (2nd: Braithwaite) that nominations for Treasurer cease and Hardin be elected by acclamation; passed. Ballots for electing a Vice-President were distributed.

3. Treasurer: Wiley asked for any comments regarding the financial statement; none came.

   Kluender recognized Art Johnson, Chair of the Auditing Committee (member: Dan England) who reported the books are in good order and praised Wiley for his excellent work this year and over the past 10 years. Motion to approve financial report passed.

4. Development Committee: Daly is working on contacts with some influential persons to obtain support for the journal.

5. Historian (Robison): This is the 81st meeting of the Arkansas Academy of Science and the fourth time to meet in Monticello; other years were 1936, 1942, 1985.

6. Biota Committee: Doug James absent; no representative or report.

7. Proceedings Editor: Trauth restated his request for continued funding ($500 for editorial assistance and $200 for travel). Approved.

8. Newsletter Editor: Saugey restated his request of $800 to support the production of the 1997-98 Newsletter. Approved.

9. Ancillary Organizations: no directors present; Kluender reviewed the reports and requests for funding introduced at the 1st meeting:
   a. Westinghouse Science Talent Search: $200
   b. Junior Science & Humanities Symposium: none
   c. Junior Academy of Science: $250
   d. Arkansas State Science Fair Association: $450

All requests were approved.

10. Kluender recognized Saugey who reported that due to recent changes, the 1998 meeting proposed for the Ramada Inn in Hot Springs will probably be far too expensive of us. Daly has consented to return to UAMS to try to reactivate their bid.

11. Kluender recognized Rickett who reviewed the motions from the *ad hoc* Constitution Committee and opened discussions:
    a. Motion (1): to eliminate the First Business Meeting. Watson suggested the first meeting be scheduled near the end of the day Friday. Braithwaite suggested we use the interned to disseminate information. Harp spoke for retaining one business meeting (2nd) and that it be rescheduled for some mid-meeting time. Johnson pointed out that we can't give out the awards at a single meeting if it's held at a mid-meeting time. Watson moved (2nd: Braithwaite) to table the motion.
    b. Motion (2): to stop giving student members a copy of the *Proceedings*. Braithwaite argued that it's important to give a firsttime presenting student a copy. McDaniel agreed that this was the reason we did it in the first place. Wiley explained the recent history of rising costs of producing the *Proceedings*. Considerable discussion followed. Braithwaite (2nd: Johnson) moved to table Motion 2. Motion to table failed. Vote on the motion: Passed.
    c. Motion (3): student membership dues be decreased to $10. No discussion came. Passed.
    d. Additional Motion: to change the journal's name to "Journal of the Arkansas Academy of Science". Passed.

12. Kluender recognized the Resolutions Committee (Rick McDaniel and George Harp): McDaniel read the resolutions (Appendix D). Hemmati moved (2nd: Robison) that the resolutions be accepted. Passed.

13. Kluender recognized Jim Huey, Chair, Awards Committee who recognized Mr. Terence Leonard (Atlantic Research Corporation in Camden on behalf of AEF to present the awards (see Appendix E).

14. Kluender recognized Wiley for a report on this meeting's statistics. No report was prepared.

15. Kluender opened the floor for old business: Saugey asked for the renewal of news from campuses for the *Newsletter*. He also asked for address and status changes.

16. Kluender announced the new Vice-President is Mostafa Hemmati and the new Treasurer is Joyce Hardin.

17. Kluender announced an item of new business: a group of concerned individuals have asked for a special subsession (mini-symposium) to report on the status of sensitive species at the next meeting. The Executive Committee will discuss it.

18. Kluender made these final announcements:
    a. Pick up unclaimed *Proceedings* and return them to respective campuses.
    b. Turn in manuscripts to Stan Trauth
    c. Personal thanks to Bob Wiley, Rose McConnell, John Rickett, Robert Watson and Jim Daly.

19. Daly moved (2nd: Trauth) that the Academy give a special award to Wiley in recognition of his 10 years as Treasurer. Approved.

20. Kluender recognized Daly and handed him the gavel as the new President. Daly thanked Kluender with a plaque.

21. President Daly then asked for input to help subsidize student members with a *Proceedings*.

Respectfully submitted,

John Rickett, Secretary 20
April 1997.

APPENDIX A

ARKANSAS ACADEMY OF SCIENCE WESTINGHOUSE SCIENCE TALENT SEARCH REPORT

Following are the winners of the 46th Annual Arkansas Science Talent Search, 1996-97, held in conjunction with the 56th Annual Westinghouse Science Talent Search:

First Place

Mi Zhou
5624 W. 31st Street #28
Little Rock, AR 72204

"Absorbance and fluorescence of copper and iron thioarbiturate complexes"

Little Rock Central High School
Sponsored by Mr. Gary Hufford

First Place

Neha Niranhan Mehta
506 Fairoaks Lane

"Comparison of the effects of epidermal growth factor,

Russellville, AR 72801 — gibberellic acid, and indole-3-acetic acid"

Arkansas School for Math and Science
Sponsored by Mr. Rodney Harris

Third Place

Fletcher Scott Foti
5018 Country Club Blvd.
Little Rock, AR 72207

"Pixel ecology: Dynamic automata as a model for forest change"

Little Rock Central High School
Sponsored by Ms. Melissa Donham

Motion from Director

"Mr. President, I move that the Arkansas Academy of Science provide up to $200 to the Arkansas Science Talent Search in order to recognize three student winners and their teachers with appropriate plaques and certificates."

Submitted by Steven W. Runge, Director
4 April 1997

APPENDIX B

ARKANSAS ACADEMY OF SCIENCE JUNIOR SCIENCE AND HUMANITIES SYMPOSIUM

The 31st Arkansas Junior Science and Humanities Symposium will be held 4-6 April 1997 at Arkansas Tech University, Russellville, AR. This will be the 21st Arkansas JSHS program held on the ATU campus. Sixteen papers from 94 submitted from across the state have been chosen for presentation and judging. The keynote speaker at the recognition banquet will be Dr. Stanley Jones from NASA Langley Research Center, Hampton, Virginia. His topic will be "NASA's Missions: To and From Earth."

The students will also hear about Dr. Mike Conner's research. The title of his presentation will be "Bobcat Ecology in a Southern Forested Ecosystem."

Several activities are planned for the 120 students and 35 teacher delegates who have been invited as guests of the symposium. The delegates will have opportunity to participate in a three-hour tour of Heifer Project International near Perryville, AR.

Submitted by Tom Palko
4 April 1997

APPENDIX C

JUNIOR ACADEMY AND STATE SCIENCE FAIR ASSOCIATION

Thank you for the support the Academy has provided for the past 14 years for AAS members being willing to serve as judges and financial support. This is a report on science fair activities in 1997:

	date location	fair director	Jr. Acad. dir.	no. part.
Central	8 March UAMS	Margie Snider	Marian Douglas	366
Northcentral	21 March Lyon Coll.	Beverly Meinzer	Kathy Campbell	179
Northeast	21,22 Mar ASU	Larry Mink	Ron Johnson	212
Northwest	14 March UAF	Lynne Hehr	Lynne Hehr	352
Southcentral	7 March HSU	Jules Mollere	Lisa Cobb	128
Southeast	7 March UAM	Jim Leslei		269
Southwest	14 March SAU	Tim Daniels		335
Westcentral	18 Feb ASMS	A. Castleberry	A. Castleberry	260

Approximately 280 students are expected to register for the State Science Fair and 75 for the state Junior Academy meeting to be held 11, 12 April in Conway (UCA). Mike Rapp will direct the fair, and Bob and Raynell Skinner will direct the Junior Academy meeting.

Please indicate a resolution of thanks for the work of the individuals indicated above.

The Arkansas Science Fair Association requests the Arkansas Academy of Science continue its support of the past 12 years of $50 to each of the science fair in Arkansas that will send students and teachers to the International Science and Engineering Fair, to be held in May 1997 in Louisville, KY. The total contribution being requested is $450. The Junior Academy of Science requests the Arkansas Academy of Science to continue its support of $250 for 1997.

Submitted by Mike Rapp
4 April 1997

APPENDIX C

ARKANSAS ACADEMY OF SCIENCE RESOLUTIONS

BE IT RESOLVED that we, the membership of the Arkansas Academy of Science, offer our sincere thanks to the University of Arkansas at Monticello for hosting the 1997 meeting of the Arkansas Academy of Science. In particular, we thank the local arrangements committee (Robert Wiley [Chair and registration], Rose McConnell [manuscripts], Jim Huey [judging of student papers], Jim Edson [audio-visual], Eric Sundell [banquet speaker], Ed Bacon [exhibitions], Walt Godwin [pre-banquet social], Morris

Bramlett [refreshments], Joe Guenter [invocation], Richard Kluender [introduction of speaker] and all of the student workers and staff who collectively contributed to a very successful meeting. Appreciation is expressed for the use of the excellent facilities and the hospitality shown to us by all Univeristy of Arkansas at Monticello personnel. The banquet was excellent with its Cajun flair, and we truly appreciated Dr. Robert C. Welsh and his graphic presentation of "Rediscovering our world with remote sensing and GIS." Certainly it was with a true touch of southern hospitality that the local arrangements committee provided continual car washes and hygienic top to bottom cleansing for participants approaching and leaving the meeting site.

The Academy recognizes the important role played by the various section chairpersons and expresses sincere appreciation to Walt Godwin (Chemistry), J. Scott McConnell (Environmental Sciences), Henry W. Robison (Vertebrate Zoology), Don Culwell (Botany and Applied Plant Sciences), Edwin Braithwaite (Physics and Geology), Wilfred Braithaite (Engineering and Mathematics), Renn Tumlison (Invertebrate and Aquatic Biology), and Russell Nordeen (Biochemistry, Genetics, Molecular Biology and Biomedical Sciences).

A special thanks is owed the individuals devoting considerable time and energy to judging student papers: Jim Huey, Vincent Cobb, Ed Bacon, Rudy Eichenberger, Joe Guenter, Mostafa Hemmati, and Jerry Webb.

The Academy appreciates the support provided by UAMS as sponsor of the pre-banquet social, the Arkansas Environmental Federation as funding sponsor of the undergraduate presentation awards, and Sigma Xi as funding sponsor of the graduate presentation awards.

We express gratitude to the various directors of the science and youth activities which are supported or supervised by the Academy: Jim Edson (Chair of the Science Education Committee), Mike Rapp (Director of the Arkansas State Science Fair Association), Tom Palko (Director of the Junior Science & Humanities Symposium), Steve Runge (Director of the Science Talent Search), and Robert and Raynell Skinner (Co-directors of the Junior Academy of Science).

We wish to thank all those who served as directors at the regional science fairs and Junior Academy meetings: Jane Meadows and Margie Snider (Central), Roberta Bustin and Beverly Meinzer (Northcentral), Larry Mink and David Gillanders (Northeast), Lynn and John Hehr (Northwest), Vince Cobb (Southcentral), Carson Davis and Joe Giddens (Southwest), Jerry Brothers (Southeast), Dana Lambert (Westcentral), and Mike Rapp (State Meeting, UCA, Conway).

The continued success of the Academy is due to its strong leadership. We offer sincere thanks to our officers for another excellent year: Richard Kluender (President), James Daly (President-Elect), Rose McConnell (Vice-President), John Rickett (Secretary), Robert Wiley (Treasurer, completing 10 years of service), Peggy Rae Dorris (Past President), Stan Trauth (*Proceedings* Editor), David Saugey (*Newsletter* Editor), and Henry Robison (Historian). In addition, the Academy expresses appreciation to all who contributed time and effort on various committees of the Academy.

Finally, we congratulate all who presented papers and posters at this meeting. Student participants are especially recognized, since their continued efforts and contributions will be directly responsible for the future success of the Academy and its programs for the continuing improvement and advancement of science education and research in Arkansas.

Respectfully submitted, Resolutions Committee
V. Rick McDaniel, Chair
George Harp

APPENDIX E

ARKANSAS ACADEMY OF SCIENCE STUDENT PAPER WINNERS

Undergraduate

Environmental Sciences

First: V.L. McTolf, UAM, "Accumulation of nitrate-nitrogen in an alfisol cropped to continuous cotton"

Second: Demetra O. Salisbury, UAF, "A hydrogeological and hydrochemical connection between Crystal Lake and Decatur City Spring, Benton County, Arkansas"

Third: J. Scott Covington, UALR, "An initial assessment of water characteristics and aquatic biota of Blanchard Spring, Stone County, Arkansas"

Life Sciences

First: Jennifer Powell, Hendrix, "Characterization of a mutation in the hPPT gene causing infantile neuronal ceroid lipofuscinosis (incl.)"

Second: Craig R. McClain, Hendrix, "The relation of size gradients with latitude in deep-sea turrids"

Third: Utah W. Nickel, Hendrix, "Induction pattern of APX3 in *Arabidopsis*"

Physical Sciences

First: Chris Barber, ASU, "Preparation of power precursors and evaporation of photoconductive indium (III) sulfide films"

Second: Brandon Kemp, ASU, "Iodide ion-based improvements in $CuInS_2$ films electrodeposited from the three solvent bath

Third: Brant Stanley, UAM, "Acidity studies of deuterated acids and bases commonly used as buffers in NMR studies"

Graduate

Life Sciences

First: Donna Moore, UAF, "Microhabitat and habitat distribution of protostelids in forests and grasslands of northwest Arkansas"

Second: Mary Lynn Lambert, E. Ill. Univ., "Characteristics and use of cavity trees in Ozark hardwood stands"

Third: Daniel White, ASU, "A comparison of vegetative growth vs. reproductive effort as an appropriate measure of aluminum phytotoxicity in *Brassica rapa*"

Physical Sciences

First: Eric Barnett, ASU, "High resolution laser spectroscopic study of jet cooled gases"

Second: Sailesh Kumar, UALR, "Thin film deposition of silicon for solar cell applications"

Third: Diana Lindquist, UAMS, "A method to correct the voxel size in press"

MEMBERS 1996

FIRST MI	LAST NAME	INSTITUTION
Robert	Bacon	University of Arkansas at Fayetteville
Max L.	Baker	University of Arkansas/Medical Sciences
Gene Lee	Bangs	University of Arkansas at Little Rock
Gwen	Barber	Arkansas Tech University
C.	Bhuvaneswaran	University of Arkansas for Medical Sciences
Victor	Blunt	University of Arkansas at Pine Bluff
Frank	Bowers	University of Wisconsin-Stevens Point
Jimmy D.	Bragg	Henderson State University
Edwin S.	Braithwaite	Cedarville College
Morris	Bramlett	University of Arkansas at Monticello
William D.	Brown	University of Arkansas at Fayetteville
Nick	Brown	University of Arkansas at Monticello
Thomas	Buchanan	Westark Community College
John	Bush	University of Arkansas at Little Rock
Susan	Cady	Arkansas State University
Michael E.	Cartwright	Arkansas Game & Fish Commission
Stanley L.	Chapman	University of Arkansas at Fayetteville
Cindy	Cisar	University of Arkansas at Fayetteville
Frances E.	Clayton	University of Arkansas at Fayetteville
Gary	Cloud	University of Arkansas
Vincent A.	Cobb	Ouachita Baptist University
Joseph T.	Collins	University of Kansas
Lynita	Cooksey	Arkansas State University
Robert M.	Cordova	Arkansas Department of Health
Marc	Corrigan	University of Arkansas at Monticello
Betty	Crump	U.S.D.A., Forest Service
Donald	Culwell	University of Central Arkansas
James T.	Daniels	Southern Arkansas University
Perry A.	Daniels	Arkansas State University
Jerry A.	Darsey	University of Arkansas at Little Rock
Jerry W.	Davis	USDA, Forest Service
Patrick	Desrochers	University of Central Arkansas
Vipul	Dholakia	University of Arkansas at Pine Bluff
Peggy Rae	Dorris	Henderson State University
Robert H.	Doster	Ark. Highway & Transp. Dept.
Benjamin T.	Duhart	University of Arkansas at Pine Bluff
Rudolph J.	Eichenberger	Southern Arkansas University
David	Eller	University of Arkansas for Medical Sciences
Robert	Engelken	Arkansas State University
Don	England	Harding University
Claude E.	Epperson	University of Arkansas/Medical Sciences
Nikola	Fijan	University of Arkansas at Pine Bluff
Sheldon	Fitzpatrick	University of Arkansas at Pine Bluff
E. P. (Perk)	Floyd	U.S. Public Health Service
Thomas L.	Foti	Natural Heritage Commission
Donald W.	Freeman	USDA-University of Ark. at Pine Bluff
Joe P.	Gentry	Arkansas Science & Technology Authority
Rose	Gergerich	University of Arkansas at Fayetteville
Elizabeth M.	Getz	University of Central Arkansas
Wayne	Gildseth	Southern Arkansas University
Crissy Patterso	Goss	Hampton High School
Wayne L.	Gray	University of Arkansas/Medical Sciences
Reid	Green	U.S. Geological Survey
Gaston	Griggs	John Brown University
Yanfei	Guo	University of Arkansas at Monticello
Earl L.	Hanebrink	Arkansas State University – retired
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Michael J.	Harvey	Tennessee Tech University
Roger M.	Hawk	University of Arkansas at Little Rock
Kristine	Herbert	Westark Community College
Larry R.	Hilburn	Black River Technical College
Lisa J.	Hlass	U.S. Forest Service
William G.	Hood	University of Arkansas at Little Rock
Feng Hou	Huang	University of Arkansas at Fayetteville
Jim	Huey	University of Arkansas at Monticello
Martin	Huss	Arkansas State University
Philip E.	Hyatt	USDA, Forest Service
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Celia	Ison	University of Nebraska
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David	Jamieson	Ark. St. University-Beebe/Newport
David	Jimerson	Arkansas State University
James E.	Johnson	University of Arkansas at Fayetteville
Michael I.	Johnson	Nettleton High School
Hugh	Johnson	Southern Arkansas University
Thurman 0.	Jordan	Arkansas Audubon Society
Jay	Justice	Ark. Dept. Pollution Control & Ecology
Alvan A.	Karlin	University of Arkansas at Little Rock
Mark	Karnes	The Ross Foundation
Philip L.	Kehler	University of Arkansas at Little Rock
Scott W.	Kirkconnell	Arkansas Tech University
Maurice G.	Kleve	University of Arkansas at Little Rock
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Roger E., II	Koeppe	University of Arkansas at Fayetteville
Randall A.	Kopper	Hendrix College
Timothy	Kral	University of Arkansas at Fayetteville
Janet	Lanza	University of Arkansas at Little Rock
Norman	Lavers	Arkansas State University
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Hal 0.	Liechty	University of Arkansas at Monticello
Brian	Lockhart	University of Arkansas at Monticello
David	Lortz	University of Arkansas at Monticello
Thomas J.	Lynch	University of Arkansas at Little Rock
Siripong	Malasri	Christian Brothers University
Jerry	Manion	University of Central Arkansas
John E.	Marshall	Biotechnical Services Inc.
H. Michael	Matthews	Henderson State University
Chris T.	McAllister	Texas Wesleyan University
Russell B.	McAllister	Ark. Dept. Pollution Control & Ecology
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Russell	Nordeen	University of Arkansas at Monticello
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James C.	Petersen	U.S. Geological Survey
Jimmie	Pigg	Oklahoma Dept. of Environmental Quality
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Alan F.	Posey	University of Arkansas at Pine Bluff
James A.	Rasmussen	Southern Arkansas University
Darryl K.	Reach	University of Arkansas at Little Rock
Scott W.	Reeve	Arkansas State University
Dennis J.	Richardson	Quinnipiac College
Joe	Rosen	University of Central Arkansas
Karen	Rowe	Arkansas Game & Fish Commission
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John	Rupe	University of Arkansas at Fayetteville
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Terry A.	Sanders	Taylor High School
Charles J.	Scifres	University of Arkansas at Fayetteville
John A.	Sealander	University of Arkansas at Fayetteville
Frank L.	Setliff	University of Arkansas at Little Rock
Elwood B.	Shade	University of Arkansas at Monticello
Ali U.	Shaikh	University of Arkansas at Little Rock
William M.	Shepherd	Arkansas Natural Heritage Comm.
Samuel	Siegel	University of Arkansas at Fayetteville
Dewey H.	Sifford	Arkansas State University
Scott	Simon	Arkansas Natural Heritage Commission
Robert	Skinner	University of Arkansas for Medical Sciences
Kimberly G.	Smith	University of Arkansas at Fayetteville
Richard D.	Smith	Arkansas State University
Roy J.	Smith, Jr.	U.S.D.A./University of Arkansas
David G.	Snyder	University of Arkansas at Monticello
Frederick W.	Spiegel	University of Arkansas at Fayetteville

Arkansas Academy of Science

FIRST MI	LAST NAME	INSTITUTION
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Eric	Sundell	University of Arkansas at Monticello
John C.	Sunderland	Arkansas Game & Fish Commission
Andrew T.	Sustich	Arkansas State University
Phil	Tappe	University of Arkansas at Monticello
William S.	Taylor	University of Central Arkansas
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D S.	Tomer	University of Central Arkansas
Faron D.	Usrey	U.S. Geological Survey
Staria	Vanderpool	Arkansas State University
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Stephen A.	Walker	The Nature Conservancy
Gerald	Walsh	
Robert L.	Watson	University of Arkansas at **Little Rock**
James 0.	Wear	V.A. Medical Center
Jerry	Webb	University of Arkansas at Monticello
Rayona	Webster	Cossatot Technical College
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Delores	Wennerstrom	Pulaski Academy
Todd	Wiebers	Henderson State University
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Heather L.	Woolverton	University of Central Arkansas
Robert D.	Wright	University of Central Arkansas
Chia C.	Yang	Arkansas Tech University
Dominic T.	Yang	University of Arkansas at Little Rock
J. Lyndal	York	University of Arkansas/Medical Sciences

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Malcolm K.	Cleaveland	University of Arkansas at Fayetteville
David	Cole	Harding University
Edward E.	Dale, Jr.	University of Arkansas at Fayetteville
David L.	Davies	University of Arkansas/Medical Sciences
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Mattie	Glover	University of Arkansas at Pine Bluff
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Daniel L.	Marsh	Henderson State University
Dennis W.	McMasters	Henderson State University
Alex R.	Nisbet	Ouachita Baptist University
Clifton	Orr	University of Arkansas/Pine Bluff
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Lawana	England-Whaley	Arkansas State University
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Walter E.	Godwin	University of Arkansas at Monticello
Joe M.	Guenter	University of Arkansas at Monticello

FIRST MI	LAST NAME	INSTITUTION
Joyce M.	Hardin	Hendrix College
George L.	Harp	Arkansas State University
Phoebe A.	Harp	Arkansas State University
Gary A.	Heidt	University of Arkansas at Little Rock
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Richard K.	Spears	Ouachita Mtns. Biological Station
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Stanley E.	Trauth	Arkansas State University
Gary	Tucker	FTN Associates
Renn	Tumlison	Henderson State University
James L.	Wickliff	University of Arkansas at Fayetteville
Robert W.	Wiley	University of Arkansas at Monticello

STUDENT MEMBERS

Jennifer	Abbott	Henderson State University
Jennifer	Akin	University of Arkansas at Fayetteville
James R.	Anderson	Henderson State University
Patricia	Anslow	U.S. Corps of Engineers
Stacy Lee	Bearden	Arkansas State University
Mohanjeet Singh	Brar	University of Arkansas at Fayetteville
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Austin B.	Richards	Arkansas State University
Demetra	Salisbury	University of Arkansas at Fayetteville
Carlos	Sanchez	University of Arkansas/Little Rock
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Chris S.	Smith	University of Arkansas at Little Rock
Frances	Terry	Arkansas Tech University
Sophia J.	Torrez	University of Arkansas at Fayetteville
Hilary J.	Worley	Arkansas State University

PROGRAM

Arkansas Academy of Science

81st Annual Meeting

April 4-5, 1997

University of Arkansas at Monticello

SCHEDULE OF EVENTS

Friday, April 4, 1997

9:00 am. - 4:00 p.m.	Registration	Lobby
1:00 a.m. - 5:00 p.m.	Exhibits	Room A-3
9:00 am. - 11:00 a.m.	Executive Committee Meeting	Room A-30
11:00 a.m. - 12:00 p.m.	First Business Meeting	Auditorium
12:00 noon - 1:30 p.m.	Lunch (See dining info at bottom of next page)	
1:30 p.m. - 5:00 p.m.	Refreshments	
1:30 p.m. - 5:00 p.m.	Paper Sessions	
	Chemistry (p. 3)	Room A-1
	Environmental Sciences (p. 5)	Room A-30
	VertebrateZoology (p. 7)	RoomB-3
	Botany & Applied Plant Sciences (p. 10)	Room B-18
1:30p.m. - 5:00p.m.	Poster Session (p. 12)	Room A-3
5:30 p.m. - 7:00 p.m.	Hospitality Gathering	Captain's Table
7:00 p.m. - 9:30 p.m.	Banquet	John F. Gibson Ctr.

Banquet Speaker
Dr. Robert C. Weih, Spatial Analysis Laboratory, School of Forest Resources, University of Arkansas at Monticello

- Rediscovering our World with Remote Sensing and GIS

Saturday, 5 April 1997

8:00 a.m. - 10:00 am.	Registration	Lobby
8:30 a.m. - 11:30 am.	Exhibits	Room A-3
8:30 a.m. - 1 1:30 p.m.	Refreshments	Room A-3
8:30 a.m. - 11:30 am.	Paper Sessions	
	Physics & Geology (p. 13)	Room A-1
	Engineering & Mathematics (p. 15)	Room A-30
	Invertebrate & Aquatic Biology (p. 17)	Room B-3
	Biochemistry, Genetics, Molecular (p. 19)	Room B18
	Biology & Biomedical Sciences	
11:30 a.m. - 12:30 p.m.	Second Business Meeting	Auditorium

Slide Preview Room: Room B-31

Sigma XI Breakfast: The traditional Sigma Xi Breakfast will be held at the El Toro Restaurant at 7:00 a.m. on 5 April 1997.

Parking Information: Parking will be available for participants in the parking lots in front of and behind the Science Center.

Dining Information: The following restaurants are located on Highway 425 traveling north from UAM: Hunans, Topps (sandwiches & pizza), Piggy Sues (barbeque), Sonic Drive-In, Pizza Hut, McDonalds, Taco Bell, Burger King, Kentucky Fried Chicken, Captain's Table Restaurant, Ray's Drive-In, El Toro Restaurant, Waff-L-Inn, Hardee's, Popeyes, Mazzio's Pizza.

SECTION PROGRAMS

*** Undergraduate **Graduate**

PAPER SESSIONS

Chemistry Paper Session
Location: Science Center Room A-1

Chairperson: Dr. Walter Godwin, Division of Mathematics and Sciences, University of Arkansas at Monticello, Monticello AR 71656.

Time	Abs. No.	Topic
1:30	CS0 1	*Brant Stanley, Rose McConnell, and Walter E. Godwin. Division of Mathematics and Sciences, University of Arkansas at Monticello, Monticello, AR 71656. **ACIDITY STUDIES OF DEUTERATED ACIDS AND BASES COMMONLY USED AS BUFFERS IN NMR STUDIES.**
1:45	CS02	* Bradley Phillips, Rose McConnell. and Walter E. Godwin. Division of Mathematics and Sciences, Universitv of Arkansas at Monticello, Monticello, AR 71656. **A MOLECULAR MODELING STUDY OF POLYMERS OF SEVERAL SUBSTITUTED FURANS.**
2:00	CS03	* Karin L.Brasfield, Vipul N. Dholatia Ray Bakhtiar, and Richard B. Walker.

		Department of Chemistry, University of Arkansas at Pine Bluff, Pine Bluff, AR 71611. **COMPLEXATION OF AN EPHEDRINE PRODRUG WITH CYCLODEXTRINS.**
2:15	CS04	Walter E. Godwin, Division of Mathematics and Sciences, University of Arkansas at Monticello, Monucello. AR 71656. **A VSEPR VISUALIZATION UTILITY USING A WEB BROWSER AND RASWIN.**
2:30	Break	
3:00	CS05	*Jerri J. Sykes, Shaheen Khan, and William M. Willingham. Research Center, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. **THE SYNTHESIS OF 5-DI-n-PROPYL SULFONAMOYL SALICYLATOMANGANESE (II) COMPLEX.**
3:15	CS06	Victor Blunt[1] John A. Kuykendall[3], William M. Willingham[1], and John Sorenson[2]. University of Arkansas at Pine Bluff[1], Pine Bluff, AR, 71601. University of Arkansas for Medical Sciences[2], Little Rock, AR 72205. **RADIOPROTECTANT ACTIVITIES OF 5-DIETHYL SULFONAMOYL SALICYLATOCOPPER (II) COMPLEX IN LD 50/30 GAMMA IRRADIATED MICE.**
3:30	CS07	Samuel M. Terry. Southside High School, Fort Smith, AR 72903. **ANTIBIOTIC RESISTANCE: THE EFFECTS OF NEW ANTIBIOTICS AND SYNERGISM ON *STREPTOCOCCUS PNEUMONIAE* AND *ENTEROCOCCUS FAECALIS* AND *ENTEROCOCCUS FAECIUM*.**
3:45	CS08	Paul Manowitz, Richard Harvey, Paul W. Stoecker, and Alexander M. Yacynych. Department of Chemistry, University of Arkansas at Little Rock, Little Rock AR 72204. **DETERMINATION OF SULFATIDE AND GALACTOCEREBROSIDE USING A GALACTOSE OXIDASE COLUMN AND ELECTROCHEMICAL DETECTION.**
4:00	CS08	Frank L. Setliff and Leslie B. Coop. Department of Chemistry University of Arkansas at Little Rock, Little Rock, AR 72204. **REDUCTIVE DECHLORINATION OF 2-CHLORONICOTINIC ACID UNDER FINKELSTEIN CONDITIONS.**

PAPER SESSIONS

Environmental Sciences Paper Session
Location: Science Center Room A-30
✲ AEF Undergraduate

Chairperson: Dr. J. Scott McConnell, Southeast Research and Extension Center, University of Arkansas, Monticello, Arkansas 71656

Time	Abs. No.	Topic
1:30	ES0 1	David G. Peitz and Philip Tappe. School of Forest Resources, Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. **RESPONSE OF SELECTED DEER BROWSE SPECIES TO THINNING OF A NATURAL LOBLOLLY PINE-HARDWOOD STAND.**
1:45	ES0 2	David G. Peitz and Philip Tappe. School of Forest Resources, Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. **EFFECTS OF RETAINED PINE AND HARDWOOD BASAL AREA ON PERCENT COVER OF PLANTS UTILIZED BY BOBWHITE QUAIL.**
2:00	ES0 3	Suzanne Wiley and Robert C. Weih. Spacial Analysis Laboratory, School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656. **INTEGRATING GIS AND REMOTE SENSING W1TH ECOSYSTEM RESEARCH.**
2:15	ES0 4	Philip A. Tappe. School of Forest Resources, Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. **USING A GEOGRAPHICAL INFORMATION SYSTEM TO EVALUATE DEER MANAGEMENT ZONES IN ARKANSAS.**
2:30	ES0 5	Philip A. Tappe[1], Ronald E. Thill[2], M. Anthony Melchiors[3], and T. Bently Wigles [4]. School of Forest Resourcesl, Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. USDA Forest Service2, Southern Research Station, Nacogdoches, TX 75962. Weyerhaeuser Company3, Hot Springs, AR 71902. National Council of the Paper Industry for Air and Stream Improvement4, Department of Aquaculture, Fisheries and Wildlife. Clemson University, Clemson, SC 29634. **LANDSCAPE-SCALE RELATIONSHIPS BETWEEN AVIAN COMMUNITIES AND FOREST M MNAGEMENT INTENSITY.**
2:45		Break
3:00	ES0 6	✲J. Scott Covington and John D. Rickett. Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **AN INITIAL ASSESSMENT OF THE WATER CHARACTERISTICS AND AQUATIC BIOTIA OF BLANCHARD SPRING, STONE COUNTY, ARKANSAS.**
3:15	ES0 7	✲Demetra O. Salisbury and Ralph K. Davis. Department of Geology, University of Arkansas at Fayetteville, Fayetteville, AR 72701. **A HYDROGEOLOGICAL**

		AND HYDRO CHEMICAL CONNECTION BETWEEN CRYSTAL LAKE AND DECATUR CITY SPRING, BENTON COUNTY, ARKANSAS.
3:30	ES0 8	*V. L. McTolf[1], J. S. McConnell[1], and W. H. Baker[2]. Southeast Research and Extension Center[1], University of Arkansas, Monticello, AR 71656. University of Arkansas Soil Testing Laboratory[2], Marianna, AR. **ACCUMULATION OF NITRATENITROGEN IN AN ALFISOL CROPPED TO CONTINUOUS COTTON.**
3:45	ES0 9	John Rickett. Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **MORPHOMETRY AND BASIC HYDROLOGY OF STREAMS ON CAMP ROBINSON MILITARY BASE.**
4:00	ES0 10	John Rickett. Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **BASIC WATER QUALITY IN STREAMS DRAINING CAMP JOSEPH T. ROBINSON MILITARY BASE.**
4:00	ES0 10	John L. Harris, Peter J. Rust, Alan C. Christian, William R. Posey II, Chris L. Davidson, and George L. Harp. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **REVISED STATUS OF RARE AND ENDANGERED MUSSELS (MOLLUSCA: MARGARITIFERIDAE, UNIONIDAE) IN ARKANSAS.**

VERTEBRATE ZOOLOGY PAPER SESSION
Location: Science Center Room B-3

Chairperson: Dr. Henry W. Robison, Department of Biology, Southern Arkansas University, Magnolia, AR 71753.

Time	Abs. No.	Topic
1:30	VZ01	David A. Saugey[1] and Daniel R. England[2]. United States Forest Service[1]. P.O. Box 189, Jessieville, AR 71949. Department of Biology[2], Southern Arkansas University, Magnolia, AR 71753. **USE OF ABANDONED WATER WELLS BY RAFINESQUE'S BIG-EARED BAT (*CORYNORHINUS RAFINESQUII*) IN SOUTHERN ARKANSAS.**
1:45	VZ02	J.D. Wilhide[1], Michael J. Harvey[2], Rick McDaniel[1], and Vernon E. Hoffman[1]. Department of Biological Sciences[1], Arkansas State University, State University, AR 72467. Department of Biology[2], Tennessee Technological University, Cookeville, TN 38505. **HIGHLAND PONDS UTILIZATION BY BATS IN THE OZARK NATIONAL FOREST, ARKANSAS.**
2:00	VZ03	Stanley E. Trauth[1] and David H. Jamieson[2]. Department of Biological Sciences[1]. Arkansas State University, State University, AR 72467. Department of Biology[2], Arkansas State University-Beebe (Newport Campus), Newport, AR 72112. **SWIMMING BEHAVIOR IN THE FOX SQUIRREL, *SCIURUS NIGER* (RODENTIA: SCIURIDAE), FROM NORTHEAST ARKANSAS.**
2:15	VZ04	Roger W. Perry[1], Ronald E. Thill[2], Phillip A. Tappe[3], and M. Anthony Melchiors[4]. USDA Forest Service[1], Southern Research Station, Hot Springs, AR 71902. USDA Forest Service[2], Southern Research Station, Nacogdoches, TX 75962. School of Forest Resources[3], Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. Southern Forestry Research Center[4], Weyerhauser Company, Hot Springs, AR 71902. **PRESENCE OF HANTAVIRUS IN SMALL MAMMALS OF THE OUACHITA MOUNTAINS.**
2:30	VZ05	Stanley E. Trauth, J. D. Wilhide, and Anthony Holt. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **POPULATION STRUCTURE AND MOVEMENTS OF ALLIGATOR SNAPPING TURTLES (*MACROCLEMYS TEMMINCKII*) FROM NORTHEASTERN ARKANSAS.**
2:45		Break
3:00	VZ06	**Jeffrey T. Briggler and Robert C. Dobbs. Department of Biological Sciences, Univeristy of Arkansas at Fayetteville, Fayetteville, AR 72701. **WATERBIRD UTILIZATION OF TWO NORTHWEST ARKANSAS RESERVOIRS.**
3:15	VZ07	Stanley E. Trauth and Hilary J. Worley. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **A SKELETOCHRONOLOGICAL STUDY OF ADULT SPINY SOFTSHELL TURTLES (*APALONE SPINIFERA*) FROM NORTHEASTERN ARKANSAS.**
3:30	VZ08	Stanley E. Trauth. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **FIRST RECORDS OF THE BLACK-MASK RACER (*COLUBER CONSTRICTOR LATRUNCULUS*) IN EASTERN ARKANSAS.**
3:45	VZ09	Henry W. Robison. Department of Biology, Southern Arkansas University, Magnolia, AR 71753. **STATUS SURVEY OF THE OZARK SHINER, *NOTROPIS OZARCANUS* MEEK IN ARKANSAS.**
4:00	VZ10	James J. Daly, Jr[1], James J. Daly[2], and H. Michael Matthews[1]. Department of Biology[1], Henderson State University, Arkadelphia, AR 71999. Department of

Microbiology and Immunology[2], University of Arkansas for Medical Sciences, Little Rock, AR 72205. **ESTIMATING YELLOW GRUB (*CLINOSTOMUM MARGINATUM*) INFECTIONS IN BLACK BASS POPULATIONS IN OZARK AND OUACHITA MOUNTAIN STREAMS BY A NON-INVASIVE TECHNIQUE.**

4:15 VZ11 Michael Payne[1] and James J. Daly[2]. Department of Pharmacology[1], University of Arkansas for Medical Sciences, Little Rock, AR 72205. Department of Microbiology and Immunology[2], Univeristy of Arkansas for Medical Sciences, Little Rock, AR 72205. **WATER QUALITY OF THE CADDO RIVER, 1994-1996.**

BOTANY AND APPLIED PLANT SCIENCES PAPER SESSION

Location: Science Center Room B-18

Chairperson: Dr. Don Culwell, Department of Bioogy, University of Central Arkansas, Conway, AR 72032

Time	Abs. No.	Topic
1:30	BP01	Phillip E. Hyatt. Kisatchie National Forest, 2500 Shreveport Hwy., Pineville, LA 71360. **ARKANSAS *CAREX* (CYPERACEAE): A BRIEFLY ANNOTATED LIST.**
1:45	BP02	Stephen A. Walker and Julian Campbell. The Nature Conservancy, 601 North University Ave., Little Rock, AR 72205. **A FLORISTIC SURVEY AND ANNOTATED CHECKLIST OF THE PINE BLUFF ARSENAL.**
2:00	BP03	Hal .O. Liechty[1], and Michael G. Shelton[2]. School of Forest Resources[1], University of Arkansas at Monticello, Monticello, AR 71656. USDA Forest Service[2], Southern Forest Experiment Station, Monticello, AR 71656. **VARIABILITY OF FOREST FLOOR NUTRIENT CONCENTRATION AND CONTENT IN MATURE PINE-HARDWOODS IN THE OUACHITA/OZARK NATIONAL FORESTS.**
2:15	BP04	*Kristy Bondurant and Joyce M. Hardin. Department of Biology, Hendrix College, Conway, AR 72032. **DNA FINGERPRINTING OF *AZOLLA*, AN AQUATIC FERN.**
2:30	BP05	**Thomas A. Nelson and Mary Lynn Lambert. Department of Zoology, Eastern Illinois University, Charleston, IL 61920. **CHARACTERISTICS AND USE OF CAVITY TREES IN OZARK HARDWOOD STANDS.**
2:45		Break
3:00	BP06	James E. Kellum[1], Eric Sundell[2], Brian R. Lockhart[1]. School of Forest Resources[1], Arkansas Forest Resources Center, University of Arkansas, Monticello, AR 71656. Division of Mathematics and Sciences[2], University of Arkansas at Monticello, Monticello, AR 71656. **GROUND FLORA COMPOSITION FOLLOWING HARVESTING OF A BOTTOMLAND HARDWOOD FOREST IN THE MISSISSIPPI RIVER-BATTURE LANDS.**
3:15	BP07	R. Kluender, M. Corrigan, and R. Weih. School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656. **USING A PC-BASED GIS SYSTEM TO ASSESS BPM COSTS.**
3:30	BP08	Chris W. Bennett and Robert C. Weih. School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656. **A METHODOLOGY FOR INTEGRATING AERIAL PHOTOGRAPHY AND LANDSAT IMAGERY FOR INVENTORY OF FOREST LAND COVER.**
4:00	BP10	**Daniel R. White and Staria S. Vanderpool. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **A COMPARISON OF VEGETATIVE GROWTH VS. REPRODUCTIVE EFFORT AS AN APPROPRIATE MEASURE OF ALUMINUM PHYTOTOXICITY IN *BRASSICA RAPA*.**
4:15	BP11	Daniel L. Marsh and Timothy A. Golden. Department of Biology, Henderson State University, Arkadelphia, AR 71999. **NEW RECORDS FOR THE DISTRIBUTION OF AN UNUSUAL LIVERWORT, *PETALOPHYLLUM RALFSII* (WILS.) NEES & GOTTSCHE (FOSSOMBRONIACEAE).**
4:30	BP12	David L. McDaniel and Daniel L. Marsh. Department of Biology, Henderson State University, Arkadelphia, AR 71999. ***PARNASSIA ASARIFOLIA* VENT. (SAXIFRAGACEAE) NEW TO ARKANSAS.**
4:45	BP13	Mohanjeet Brar, Teddy Morelock, and Edwin Anderson. Department of Plant Pathology, University of Arkansas at Fayetteville, Fayetteville, AR 72701. **THE EFFECT OF MEDIA CONSTITUENTS ON IN VITRO CULTURING COWPEA *(VIGNA UNGUICULATA)* SHOOT TIP AND LEAF EXPLANTS.**

POSTER SESSION

Location: Science Center Room A-3

Time	Abs. No.	Topic
1:30	PS01	Daniel R. England[1] and David A. Saugey[2]. Department of Biology[1], Southern Arkansas University, Magnolia, AR 71753.

United States Forest Service[2], Jessieville, AR 71949. **A METHOD TO REMOVE BATS FROM CASED WATER WELLS.**

PAPER SESSIONS

PHYSICS AND GEOLOGY PAPER SESSION

Location: Science Center Room A-1

Chairperson: Dr. Edwin Braithwaite, Department of Sciences and Mathematics, Cedarville College, Cedarville, OH 45314

Time	Abs. No.	Topic
8:30	PG01	*Mathues Shane Doss and Mostafa Hemmati. Department of Physical Science, Arkansas Tech University, Russellville, AR 72801. **BREAKDOWN WAVES: EFFECT OF CURRENT ON ELECTRON TEMPERATURE AND NUMBER DENSITY.**
8:45	PG02	*Nicholas J. Pfister, Sue Ellen McCloskey, and Wilfred J. Braithwaite. Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204. **CALCULATING TIDAL FORCES WITHIN THE SOLAR SYSTEM.**
9:00	PG03	*Danny R. Crawford, Charles W. Ford, Jr., and Wilfred J. Braithwaite. Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204. **SCIENTIFIC COMPUTING USING LINUX AT UNIVERSITY OF ARKANSAS AT LITTLE ROCK.**
9:15	PG04	*Tamra Pool[1], Leo Carson Davis[1], and Kenneth M. Ball[2]. Department of Physical Sciences[1], Southern Arkansas University, Magnolia, AR 71753. El Dorado High School[2], El Dorado, AR 71730. **ANOMALOUS VERTEBRATE FOSSILS FROM PECCARY CAVE, NEWTON COUNTY, ARKANSAS.**
9:30	PG05	Edwin S. Braithwaite[1] and Wilfred J. Braithwaite[2]. Department of Science and Mathematics[1], Cedarville College, Cedarville, OH 45314. Departmentof Physics and Astronomy[2], University of Arkansas at Little Rock, Little Rock, AR 72204. **CALCULATING TWO VERTICES FROM COPLANARITY OF EMERGING PAIRS.**
9:45		Break
10:15	PG06	Leo Carson Davis[1] and Kathy Harris[2]. Department of Physical Sciences[1]. Southern Arkansas University, Magnolia, AR 71753. Department of Psychology[2]. Emporia State University, Emporia, KS 66801. **DISCOVERY OF FOSSIL CRETACEOUS BIRD IN SOUTHWEST ARKANSAS.**
10:30	PG07	**H. Eswaran[1], J. D. Wilson[1], R. M. Hawk[1], and C. L. Lowery[2]. Department of Applied Science[1], University of Arkansas at Little Rock, Little Rock, AR 72204. Department of Ob/Gyn[2], University of Arkansas for Medical Sciences, Little Rock, AR 72205. **RECORDING OF AUDITORY EVOKED POTENTIALS IN THE HUMAN FETUS.**
10:45	PG08	D. T. C. Yang and C. J. Zhang. Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72212. **ULTRASOUND AND MICROWAVE ASSISTED OXIDATION OF CYCLOHEXANONE TO ADIPIC ACID WITH CHLOROX.**

ENGINEERING AND MATHEMATICS PAPER SESSION

Location: Science Center Room A-30

Chairperson: Dr. Wilfred Braithwaite, Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204.

Time	Abs. No.	Topic
8:30	EM01	**Diana Lindquist[1], Richard Komoroski[2], and Roger Hawk[1]. Department of Applied Sciences[1], University of Arkansas at Little Rock, Little Rock, AR 72204. Departments of Radiology and Biochemistry[2], University of Arkansas for Medical Sciences, Little Rock, AR 72205. **A METHOD TO CORRECT THE VOXEL SIZE IN PRESS.**
8:45	EM02	**Sailesh Kumar and Roger M. Hawk. Department of Applied Science, University of Arkansas at Little Rock, Little Rock, AR 72204. **THIN FILM DEPOSITION OF SILICON FOR SOLAR CELL APPLICATIONS.**
9:00	EM03	**Eric Barnett, Philip Williams, Brian Stanley, Tony Bednar, and Scott Reeve. Department of Chemistry, Biochemistry and Physics, Arkansas State University, State University, AR 72467. **HIGH RESOLUTION LASER SPECTROSCOPIC STUDY OF JET COOLED GASES.**
9:15	EM04	**Mark-Anthony Conti, Charles R. Bowlus, and Wilfred J. Braithwaite. Department of Physics and Astronomy, University of Arkansas at Little Rock, Little Rock, AR 72204. Department of Biopharmaceutical Sciences[2], University of Arkansas for Medical Sciences, Little Rock, AR 72205. **PREDICTION OF POTENTIAL ANTIMIGRAINE ACTIVITY BY USING ARTIFICIAL NEURAL NETWORKS.**
9:45		Break
10:00	EM06	Wilfred J. Braithwaite[1] and Edwin S. Braithwaite[2]. Department of Physics and Astronomy[1], University of Arkansas at Little Rock, Little Rock, AR 72204. Department of Science and Mathematics[2], Cedarville College, Cedarville, OH 45314.

		IDENTIFYING KAONS & PIONS VIA MOMENTUM CONSERVED MUON DECAY.
10:15	EM07	*Chris Barber[1], R. Engelken[1], W. Aleem[1], B. Kemp[1], I. Khan[1], C. Edrington[1], M. Buck[1], Tom Jakobs[2]. Department of Engineering[1], Arkansas State University, State University, AR 72467. InvoTek, Inc.[2], Alma, AR. **PREPARATION OF POWER PRECURSORS AND EVAPORATION OF PHOTOCONDUCTIVE INDIUM (III) SULFIDE FILMS.**
10:30	EM08	*Brandon Kemp, R. Engelken, C. Edrington, W. Aleem, I. Khan, C. Barber, M. Buck. Department of Engineering, Arkansas State University, State University, AR 72467. **IODINE ION-BASED IMPROVEMENTS IN $CuInS^2$ FILMS ELECTRODEPOSITED FROM THE THREE SOLVENT BATH.**
10:45	EM09	*Imran Khan, R. Engelken, W. Aleem, C. Barber, C. Edrington, and M. Buck. Department of Engineering, Arkansas State University, State University, AR 72467. **FURTHER OPTIMIZATION OF NONAQUEOUS BATHS FOR CHEMICAL PRECIPITATION DEPOSITION OF CdS FILMS.**
11:00	EM10	Sanjay K. Mitra, Qing Luo, and Jerry Darsey. Department of Chemistry, University of Arkansas at Little Rock, Little Rock, AR 72204. **ARTIFICIAL NEURAL NETWORKS USED TO PREDICT ELECTRICAL PROPERTIES OF POLYMERS.**

INVERTEBRATE AND AQUATIC BIOLOGY PAPER SESSION
Location: Science Center Room B-3

Chairperson: Renn Tumlison, Department of Biology, Henderson State University, Arkadelphia, AR 71999.

Time	Abs. No.	Topic
8:30	IA01	*Craig Robert McClain[1], Michael Rex[2], and Joyce Hardin[1]. Departmentof Biology[1], Hendrix College, Conway, AR 72032. University of Massachusetts at Boston[2], Boston, MA 02125. **THE RELATION OF SIZE, GRADIENTS WITH LATITUDE IN DEEP-SEA TURRIDS.**
8:45	IA02	*Martha McHenry, Janet Lanza, and Michael Warriner. Department of Biology, University of Arkansas at Little Rock, Little Rock, AR 72204. **REPRODUCTION BY *PIERIS RAPAE* INCREASES WHEN PROVIDED WITH AMINO ACID RICH NECTAR.**
9:00	IA03	*Richard D. Smith[1] and George L. Harp[2]. 44 Spring Grove Dr., Sherwood, AR 72120[1]. Department of Biological Sciences[2], Arkansas State University, State University, AR 72467. **AQUATIC MACROINVERTEBRATES OF WARREN PRAIRIE, BRADLEY AND DREW COUNTIES, AKRANSAS.**
9:15	IA04	George L. Harp. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **THE ODONATA (DRAGONFLIES) OF THE TROPICAL DRY FOREST. II. THE CHAMELA, MEXICO AREA.**
9:30	IA05	Thomas M. Buchanan. Department of Biology, Westark Community College, Fort Smith, AR 72913. **THE FISH COMMUNITY IN INDIAN BAYOU, A COASTAL PLAIN STREAM OF REMARKABLE SPECIES RICHNESS IN THE LOWER WHITE RIVER DRAINAGE OF ARKANSAS.**
9:45		Break
10:00	IA06	Rosalyne Davis and Ronald L. Johnson. Department of Biological Sciences, Arkansas State University, State University, AR 72467. **A STUDY OF AGE, GROWTH AND CONDITION OF LARGEMOUTH BASS, *MICROPTERUS SALMOIDES*, OF LAKE ASHBAUGH.**
10:15	IA07	Renn Tumlison and James Anderson. Department of Biology, Henderson State University, Arkadelphia, AR 71999. **APPARENT CHANGES IN THE FISH FAUNA OF THE CADDO RIVER BELOW DEGRAY LAKE OVER A 25 YEAR PERIOD.**
10:30	IA08	**Donna L. Moore and F. W. Spiegel. Department of Biological Sciences, University of Arkansas at Fayetteville, Fayetteville, AR 72701. **MICROHABITAT AND HABITAT DISTRIBUTION OF PROTOSTELIDS IN FORESTS AND GRASSLANDS OF NORTHWEST ARKANSAS.**
10:45	IA09	**Rayona Webster. Cossatot Technical College, De Queen, AR 71832. **A PROPOSED NEW GENUS & SPECIES *SPINEAGLOBULA RECURVATA* N. SP. (EUMYCETOZOAN), A BARK INHABITING PROTOSTELIDA.**
11:00	IA10	**Steve P. Fillip and Todd Wiebers. Department of Biology, Henderson State University, Arkadelphia, AR 71999. **GROWTH AS A FUNCTION OF DIET IN OSCARS (*ASTRONOTUS OCELLATUS*).**
11:15	IA11	**Cris L. Davidson, George L. Harp, and John L. Harris. Arkansas State University, Department of Biological Sciences, State University, AR 72467. **A SURVEY OF MOLLUSCA (BIVALVIA: UNIONACEA) INHABITING MYATT CREEK, FULTON COUNTY, ARKANSAS.**

BIOCHEMISTRY, GENETICS, MOLECULAR BIOLOGY AND BIOMEDICAL SCIENCES PAPER SESSION

Location: Science Center Room B-18

Chairperson: Dr. Russell Nordeen, Division of Mathematics and Sciences, University of Arkansas at Monticello, Monticello, AR 71656.

Time	Abs. No.	Topic
8:30	BB01	John T. Daniels and Russell O. Nordeen. Division of Mathematics and Sciences, University of Arkansas at Monticello, Monticello, AR 71656. **ANALYSIS OF TRANSPOSON MUTAGENESIS OF THE TOMATO PATHOGEN *PSEUDOMONAS SYRINGAE.* PV *TOMATO.***
8:45	BB02	Xin Y. Li[1], Feng H. Huang[1], and Edward Gbur, Jr.[2]. Department of Horticulture[1], University of Arkansas at Fayetteville, Fayetteville, AR 72701. Agricultural Statistics Lab[2], University of Arkansas at Fayetteville, Fayetteville, AR 72701. **EFFECTS OF ACETOSYRINGONE, pH AND GLUCOSE ON TRANSIENT TRANSFORMATION EFFICIENCY OF POPULAR HYBRID.**
9:00	BB03	Vipul N. Dholakia and Richard B. Walker. Department of Chemistry, University of Arkansas at Pine Bluff, Pine Bluff, AR 71611. **EFFECTS OF BETA-HYDROXYPROPYL CYCLODEXTRIN ON THE CENTRAL STIMULANT EFFECTS OF (-)- EPHEDRINE AND AN EPHEDRINE PRODRUG IN RATS.**
9:15	BB04	*Dwight D. Thomas, Mattie M. Glover, Clifton Orr, and Cynthia D. Burroughs. Department of Biology, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. **SENSITIVITY OF HUMAN BLADDER CANCER CELLS TO PLATINUM ANTICANCER DRUGS.**
9:30	BB05	*Jennifer R. Powell and Joyce M. Hardin. Department of Biology, Hendrix College, Conway, AR 72032. **CHARACTERIZATION OF A MUTATION IN THE hPPT GENE CAUSING INFANTILE NEURONAL CEROID LIPOFUSCINOSIS (INCL).**
9:45		Break
10:00	BB06	*Utah W. Nickel[1], Hong Zhang[2], Joyce M. Hardin[1]. Department of Biology[1], Hendrix College, Conway, AR 72032. Texas Tech University[2], Lubbock, TX 79409. **INDUCTION PATTERN OF *APX3* IN *ARABIDOPSIS.***
10:15	BB07	*Rob C. Baker[1], Joyce M. Hardin[1], and Mike Ostrowski[2]. Department of Biology[1], Hendrix College, Conway, AR 72032. Ohio State University[2], Columbus, OH 43210. **ACTIVATED RAS INDUCES TRANSCRIPTION OF THE -88/+79 OPN PROMOTER IN 3T3 CELLS.**
10:30	BB08	*Torrance Walker, Christy Washington, Dedric Hayes, B. Hwflich, B. Green, and Y. Yerokun. Research Center, University of Arkansas at Pine Bluff, Pine Bluff, AR 71601. National Center for Toxicological Research, Jefferson, AR 72079. **CHARACTERIZATION FOR THE RECOMBINANT VECTORS EXPRESSING THE SULFONOTRANSFERASE GENE TRANSFECTION INTO MAMMAMALIAN CELLS.**
10:45	BB09	Lynita M. Cooksey[1], Stacy L. Bearden[2], and Larry R. Hilburn[2]. Department of Biological Sciences[1], Arkansas State University, State University, AR 72467. Department of Entomology[2], Louisiana State University, Baton Rouge, LA 70803. Black River Technical College[1], Pocahontas, AR 72455. **GENETIC VARIATION IN POPULATIONS OF *ANOPHELES QUADRIMACULATUS* AND *PSOROPHORA COLUMBIAE* IN NORTHEASTERN ARKANSAS.**
11:00	BB10	Timothy Hodge and Ronald L. Johnson. Department of Biological Science, Arkansas State University, State University, AR 72467. **GENETIC DISTANCE BETWEEN THE LARGEMOUTH, SMALLMOUTH AND SPOTTED BASSES (GENUS *MICROPTERUS*) AS DETERMINED BY MITOCHONDRIAL DNA ANALYSIS.**
11:15	BB11	Stephen R. Skinner[1], and Robert D. Skinner[2]. University of Arkansas at Fayetteville[1], Fayetteville, AR 72701. University of Arkansas for Medical Sciences[2], Little Rock, AR 72205. **ENTRAINMENT OF THE RESPIRATORY SYSTEM DURING CYCLING EXERCISE.**

Preparation of Powder Precursors and Evaporation of Photoconductive Indium Sulfide Films

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Abstract

We have demonstrated significant photoconductance in indium sulfide thin films prepared by thermal vacuum evaporation of In_2S_3 powders synthesized in-house by chemical precipitation of $InCl_3$ or In $(CH_3COO)_3$, and $(NH_4)_2S$ or Na_2S. The $\Delta G_\lambda/G_{Dark}$ values have been as high as 0.1 in the initial unoptimized films. Excess sulfur (via a mixture of polysulfide and sulfide ions in the synthesis bath) appears to be important in achieving reproducible and large photoconductivities. In_2S_3 is particularly attractive as a lower toxicity alternative to CdS in optoelectronic applications such as photovoltaic and photoconductive cells.

Introduction

In_2S_3 is an n-type semiconductor of yellow/orange color and bandgap near 2.0 eV (Bylander, 1971). Our group's recent emphasis (Siddiqui, et al., 1995; Johnson, et al., 1997) on development/identification of potentially lower hazard/toxicity photoconductors motivated us to investigate this previously little-studied semiconductor as a material that has (l) just recently received some attention as a low toxicity substitute for CdS in solar cells (Braunger et al., 1996), (2) would allow some transparency in the red/orange portion of the visible spectrum, and (3) still exhibit substantial photoconductivity in the yellow-to-violet part of the spectrum. Our initial work involved thermal vacuum evaporation of commercial In_2S_3 powders at 10^{-5} - 10^{-4} torr which yielded photoconductive films. However, later runs with supposedly identical material (99.999%) from a more recent lot/order from the same supplier as well as from material of comparable purities from several different suppliers led to radically variable results; some material yielded no photoconductance and some was as good as the initial runs. A serendipitous observation was made when one supplier who was out of "standard" In_2S_3 offered us some from an "experimental" lot that, based upon its analysis, did not meet the intended 99.999% purity (they estimated 99.99% purity), but was sulfur-rich. This material, when evaporated, produced films with the largest photoconductances (ΔG_λ) yet ($\Delta G_\lambda/G_{Dark} > 0.1$, where G_{Dark} is the ambient, unilluminated film conductance).

This led us to attempt in-house synthesis of our own material which would be made sulfur rich by dissolving elemental sulfur in $(NH_4)_2S$ or Na_2S solutions to yield up to 10% (relative to the S_1^{-2} concentration) polysulfide (primarily S_2^{-2}) in the primarily S^{-2}-bearing solution used to form In_2S_3 by mixing with a separate solution of In(III). The hypothesis was that some $In_2(S_x)_3$ ($x > 1$) (indium polysulfide) molecules would form in the In_2S_3 matrix which, when subsequently evaporated, would produce the sulfur richness in the film that appeared to enhance photoconductivity, as well as shifting the equilibrium away from possible formation of the other indium sulfide phases InS and In_2S and toward In_2S_3. The hypothesis was verified in that such films were reproducibly photoconductive ($\Delta G_\lambda/G_{Dark}$ from 0.01-0.1) in contrast to those prepared from commercial material from different lots and/or different manufacturers.

Although evaporation onto low temperature substrates under these conditions might be expected to yield films with mixed phases (In_2S_3, InS, In_2S, In, and S), higher substrate temperatures would be expected to activate (l) complete reaction between the plentiful sulfur and any In_2S, InS, or even In that might form upon dissociation of In_2S_3 upon evaporation to drive the film stoichiometry to "completion" (i.e., In_2S_3) and (2) completely revolatilize into the vapor phase any segregated elemental sulfur phases that might

transiently form on the substrate due to either the excess sulfur or sulfur molecules formed by dissociation of the In_2S_3 upon evaporation (i.e., $In_2S_3 = In_2S + S_2$).

The decomposition of the In_2S_3 powder into other indium sulfide phases and sulfur upon resistive heating in the molybdenum boats was implied by (l) the darkening of the powder from bright orange to dark gray/brown, (2) occasional appearance of an initial white/yellow elemental sulfur "cloud" or film, and (3) occasional formation of indium-rich darker brown-orange (vs. the standard bright orange) films.

Materials and Methods

In_2S_3 powders were formed by mixing separate aqueous solutions of $InCl_3$ or $In(CH_3COO)_3$, and $(NH_4)_2S$ or Na_2S. No large difference in the photoconductances of the subsequent films was found between the various reagents although those arising from the $In(CH_3COO)_3$, and $(NH_4)_2S$ appear to be slightly more photoconductive (perhaps, due to an absence of trace Na^+ and/or Cl^- incorporation). HCl or CH_3COOH was slowly added to the In(III) bath until any cloudy color disappeared (pH<≈1.8). The pH of the S(-II) baths was adjusted to between 7 and 8 (to avoid H_2S formation). Elemental sulfur (up to 10% by molarity relative to the S(-II)) was then added to the S(-II) bath and mildly heated and stirred until it completely dissolved as polysulfides (S_x^{-2} and/or HS_x^{-1}, x = 1-7 with x = 2 probably dominant) due to association/reaction with the S(-II) (S^{-2} or HS^{-1}). Usually the molarity of the In(III) was of order 0.1 M with the combined S^{-2}/S_x^{-2} molarity greater (up to three times), thereby minimizing any chance of In_2O_3, $In(OH)_3$, or other possible low solubility indium phases "contaminating" the resultant In_2S_3 (i.e., we wanted to make sure that there was "plenty" of S^{-2}/S_x^{-2} to precipitate with the In(III)). Usually, concentrations and volumes were calculated to yield 2-5g of In_2S_3 per run. Upon mixing, the combined solution was rapidly stirred and the pH quickly increased to 7-8 via NH_4OH addition (to avoid loss of S(-II) via H_2S). A yellow/orange $In_2S_3/In_2(S_x)_3$ precipitate rapidly formed upon mixing. After several minutes, the stirring was turned off and the precipitate isolated by filtering through a standard Hirsch filter/funnel with running water activated vacuum. Up to five followup washes/ rinses with distilled water while mixing the In_2S_3 "mud"/"paste" were made to flush out any residual soluble salts ($Na(CH_3COO)$, NaCl, $NH_4(CH_3COO)$, NH_4Cl, Na_2S, $(NH_4)_2S$, $InCl_3$, or $In(CH_3COO)_3$) from the indium sulfide. The powder was then dried under a heat lamp in air and then rebroken into a powder by manual stirring and/or mortar and pestle methods. Reagent purities ranged from 99.9% to 99.999% and were provided by Alfa/Johnson-Matthey, Aldrich, Fluka, and Cerac. Commercial distilled water was used for bath preparation.

The powder was subsequently placed in "V"-shaped molybdenum troughs/boats made in-house from Mo sheet metal and connected to the resistive heating power supply in our Kurt J. Lester Co. vacuum deposition unit with turbomolecular pump. Substrates were clamped roughly 15 cm. above the boat on a substrate stand/heater assembly controlled by an Omega temperature controller with platinum RTD temperature sensor. The unit was pumped down to between 10^{-5} and 10^{-4} torr, and the current of the boat slowly ramped manually until it began to glow orange and the In_2S_3 powder particles vibrated/"danced". At this point the In_2S_3 sublimed without melting and recondensed on the substrate surface as an orange film.

Substrates included both copper-clad printed circuit boards and Cu-on-Cr-on-glass pieces on which interdigitated, "comb-like" metal contacts had been defined by previous PC board processing methods and transparent/conductive Donnelly indium tin oxide-on-glass with alternating conductive ITO and insulting gaps, also delineated by PCB technology. Substrate temperatures during deposition ranged from room temperature to 280°C, and photoconductances were observed for films grown over the entire temperature range.

Deposition times typically ranged from 3-5 minutes or until all of the In_2S_3 powder was consumed (or vibrated out of the boat). Thickness/color was monitored visually via a glass microscope slide placed to the side of the primary substrates but still in the evaporation effluent "cone." Upon the films reaching adequate thickness, the boat and heater currents were set to zero and the substrates were allowed to cool for up to an hour while still in vacuum (to avoid reaction with O_2) prior to venting the bell jar to atmosphere. Then the bell jar and substrates were removed and the films inspected, labeled, and stored prior to subsequent characterization. The films were usually a bright orange color but were yellow when very thin, nearly red (and very flaky/non-adherent) when very thick (~1 μm), and a darker orange-brown when substantially indium-rich.

Photoconductivity Measurements

The films were characterized by mounting in our custom photoconductivity apparatus (Fig. 1) containing an operational amplifier circuit producing an output voltage directly proportional to the conductance, G, of the sample: $v_o = -GR_F v_{in}$. A solid state laser diode (≈ 2mW) at the He-Ne laser wavelength (633 nm) was modulated by a computer controlled driver circuit to yield light pulses of variable duty cycle and intensity for measurement of the photoconductance. Typically, we ran at 95% of full power with a "train" of 50 μs-on and 100 μs-off light pulses separated by several ms between trains. This produced both high frequency and low frequency components in the pho-

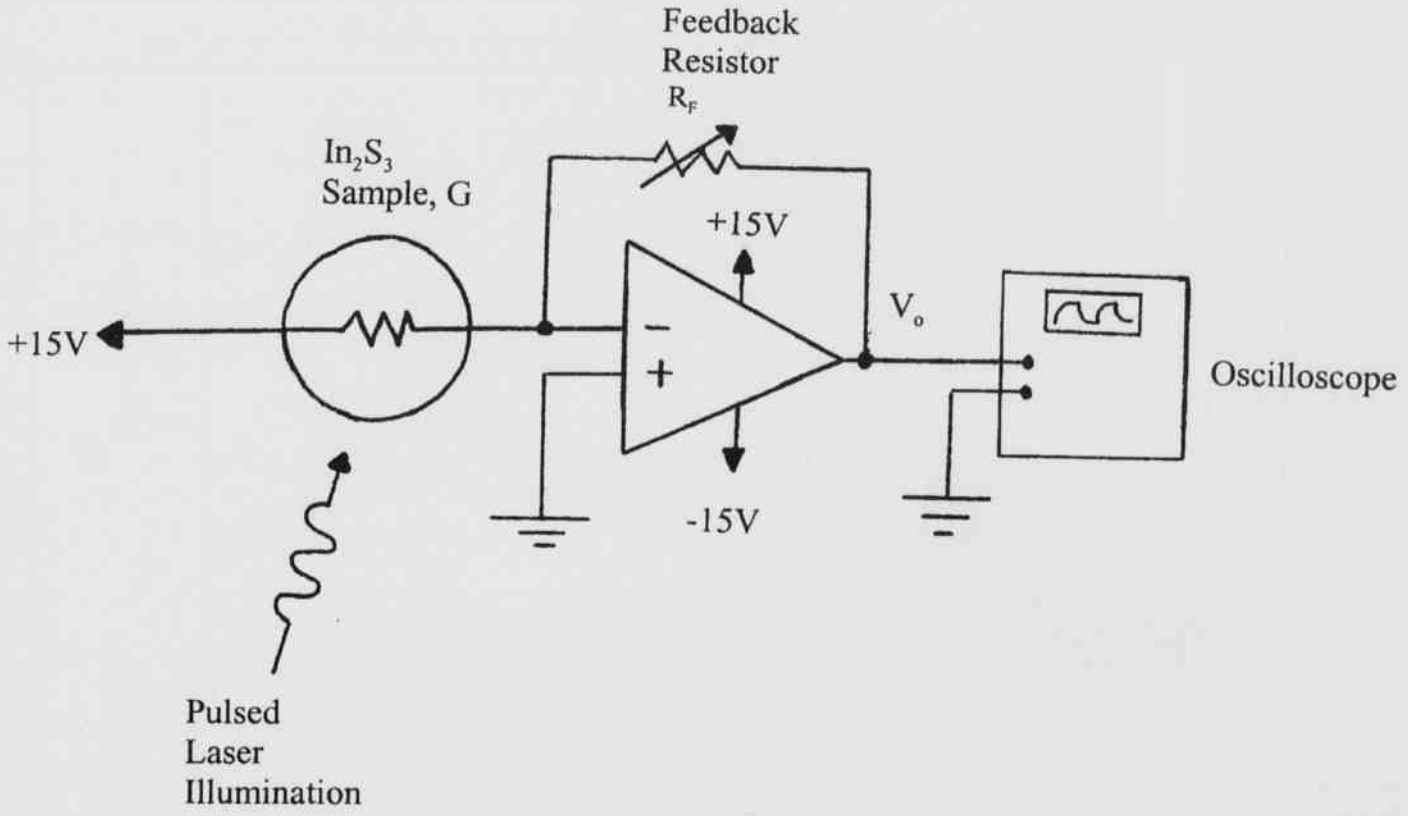

Fig. 1. Schematic diagram of photoconductance measurement apparatus: $v_o = -15\ G\ R_F$ (V) and $\Delta v_o = -15\ \Delta G\ R_F$ (V).

tovoltage signal (Fig. 2). Typical DC bias voltages (v_{in}) between the two conductive contacts were 15 V with feedback resistances (R_F) from 10 kΩ to 10 MΩ. These allowed convenient measurement of photoconductance, ΔG_λ, and dark conductance, G_{Dark}, values in the 10^{-6} to 10^{-10} range (depending upon sample thickness and area) by direct analysis of the photovoltage or dark voltage on an oscilloscope after an additional 1000 x amplification just before the oscilloscope. Typical $\Delta G_\lambda / G_{Dark}$ values ranged from 10^{-2} to 10^{-1} regardless of whether $InCl_3$ or $In(CH_3COO)_3$, or $(NH_4)_2S$ or Na_2S were used in the synthesis. Increasing excess sulfur (as polysulfide) in the synthesis bath improved photoconductance as long as small (< 10% of the S(-II) concentration). A greater excess led to initial evaporation of an elemental sulfur layer as the boat was slowly ramped up in temperature prior to In_2S_3 evaporation; a white-yellow sulfur "cloud" inside the bell jar resulted in a sulfur film on everything and increased cracking/ flaking of the film. The time constant of the quasi-exponential rise and decay of the photoconductance (measured on the low frequency component of the photovoltage waveform) was typically in the hundreds of microseconds range, indicating In_2S_3 as a potentially high bandwidth photoconductor.

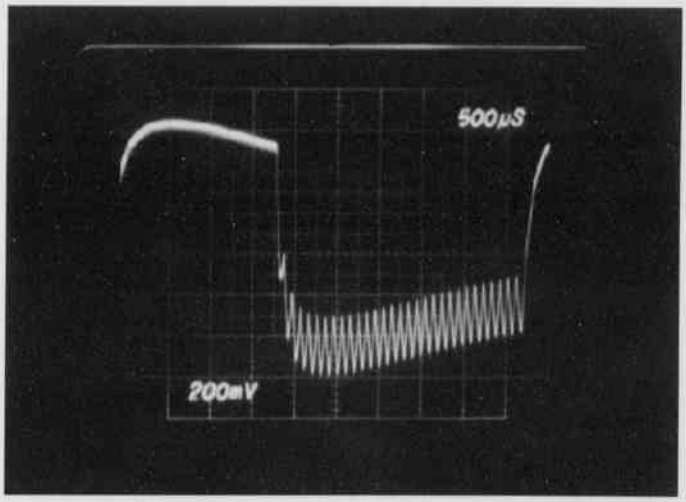

Fig. 2. Oscilloscope photograph of a typical photovoltage signal from an In_2S_3 film evaporated on/between interdigitated copper contacts on fiberglass printed circuit board.

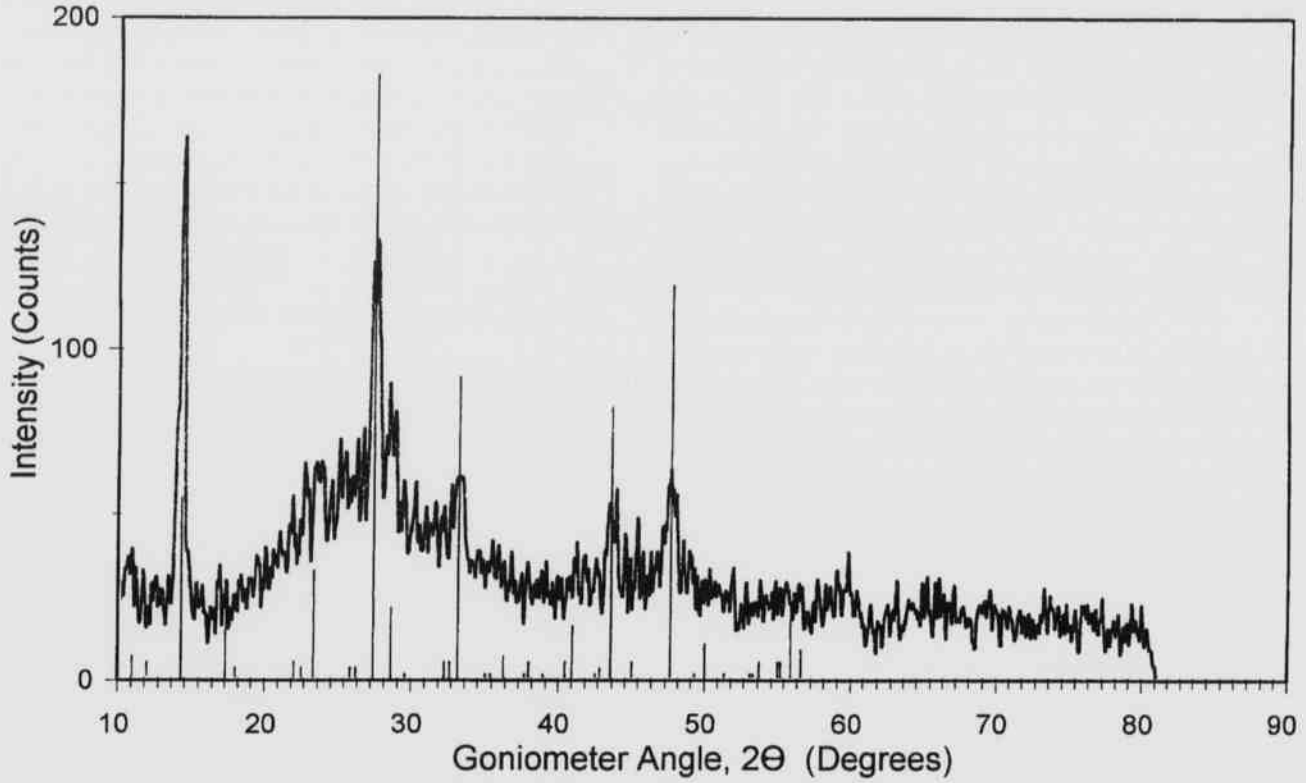

Fig. 3a. X-ray diffraction spectrum for an In_2S_3 film (bright orange) evaporated onto a glass microscope slide at 280°C. Note the excellent agreement between the dominant peaks and the vertical lines representing the In_2S_3 powder diffraction card standard (#25-390).

Other Characterization

Figures 3a and 3b exhibit typical x-ray diffraction spectra of bright orange In_2S_3 films grown at 280°C and 21°C, respectively, on glass microscope slides as measured on a Rigaku DMAX II X-ray diffractometer (Cu-kα). The dominant peaks on Figure 3a match with the vertical lines for In_2S_3 Powder Diffraction File Card 25-390 whereas Figure 3b exhibits little or no peak structure consistent with a nearly amorphous material grown at room temperature. Figures 4a and 4b exhibit plots of optical absorbance vs. wavelength for the same films as with Figures 3a and 3b, as measured on a Perkin-Elmer Lambda 19 spectrophotometer. The rapid increases in absorbance near 600 nm are consistent with In_2S_3's reported bandgap of 2.0 eV, albeit with some sub-bandgap absorbance "tailing" and "interference ripple."

Figure 5 exhibits energy dispersive x-ray analysis (EDAX) data for a film grown with a glass substrate temperature of 200°C and having a darker brown-orange color. This film was minimally photoconductive. Of particular interest is the fact that the gross film stoichiometry (46.91% In/53.09%S) is closer to InS (50% In/50%S) than In_2S_3 (40% In/60% S). Figure 6 exhibits an x-ray diffraction spectrum for this film. Surprisingly, in spite of indium richness, there is still and only a match with the In_2S_3 lines (just as with Figure 3a) rather than with those for InS, perhaps implying a mixture of In_2S_3 crystallites with an amorphous indium-rich In_xS ($x > 2/3$) matrix. Figure 7 exhibits an optical absorbance versus wavelength spectrum for this film. Note that the foot of the absorption edge has been shifted from near 600 nm to over 700 nm, consistent with either extensive band tailing and/or a reduction in bandgap due to the excess indium.

The data is consistent with the fact that In_xS and S_x(x predominately 2) vapors form upon evaporation of In_2S_3. Evidently, there is a tendency for mixed stoichiometries between the equilibrium In_2S_3 and InS phases unless the excess elemental sulfur content of the starting powder is significant; that is, as both In_2S and S_x condense on the substrate, they react to form subsequent InS, In_2S_3 and, perhaps, metastable intermediate phases. Only if "extra" S is present in the vapor stream will the stoichiometries be shifted completely to the highly photoconductive In_2S_3 (the bright orange phase vs. the darker brown-orange In-rich material).

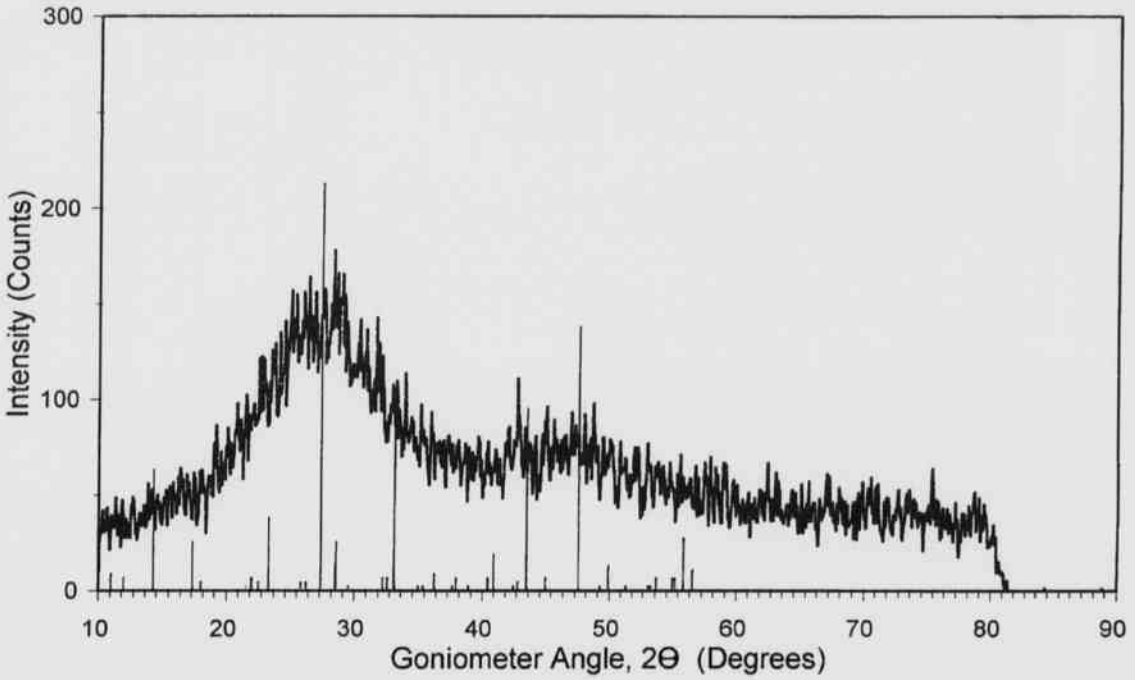

Fig. 3b. X-ray diffraction spectrum for an In_2S_3 film (bright orange) evaporated onto a glass microscope slide at room temperature. The large, broad peak centered near 26° is due to the glass substrate. The absence of the In_2S_3 peaks (denoted by the vertical lines) indicates nearly amorphous, probably sulfur-rich material.

Conclusions and Future Work

We have conducted "pioneering" research on synthesis of In_2S_3 powders and subsequent thermal vacuum evaporation of such as indium sulfide films on substrates with copper or indium tin oxide contacts to form photoconductive cells. Reproducible photoconductances were obtained over a broad range (21-280°C) of evaporation temperatures with a "figures-of-merit" $\Delta G_\lambda/G_{Dark}$ ratios in the 10^{-2} to 10^{-1} range and time constants in the hundreds of μs range when illuminated with pulsed 2 mW laser radiation at 633 nm. Excess sulfur significantly enhances the reproducibility and value of the photoconductance probably due the minimization of insoluble oxide, hydroxide, carbonate, chloride, or mixed phases of In and Na or other sulfur-deficient phases of indium sulfide (InS, In_2S) in the powder and/or film (as probably occur in some commercial material close to "perfect" 2:3 In:S stoichiometry) and, possibly, also due to minimization of sulfur vacancies in the n-In_2S_3; that is, excess chalcogen generally acts as an acceptor to make an n-type material less n-type, more intrinsic, and, hence, more photoconductive. X-ray diffraction and optical absorbance vs. wavelength measurements are consistent with semiconducting In_2S_3 with a bandgap near 2.0 eV. Without sufficient excess sulfur in the starting powder, the films tend to be slightly indium-rich, minimally photoconductive, and of a darker brown-orange color.

Future work will involve doping/sensitizing the In_2S_3 with copper, silver, and tellurium, detailed annealing and light soak studies, and optimization of the sulfur excess toward maximum photosensitivity. In_2S_3 appears to offer much potential as a photosensitive optoelectronic material "tuned" to the middle of the visible spectrum.

ACKNOWLEDGMENTS.—We acknowledge the gracious support provided by the National Institutes of Health through Phase II SBIR and Phase I STTR grants administered through InvoTek, Inc., and by the AR/NASA EPSCoR Program through the Arkansas Advanced Photovoltaic Materials Research Center (Dr. Hameed Naseem-Director, Dr. Gaylord Northrop and Dr. Keith Hudson-State Coordinators, and Dr. Dennis Flood-NASA Lewis Research Center Photovoltaics Branch (Cleveland, OH)-NASA Mentor). We thank Mr. F. Scott Miller at the University of MissouriRolla for the EDAX data. We also are grateful for the ongoing support provided by Arkansas State University and its administrators.

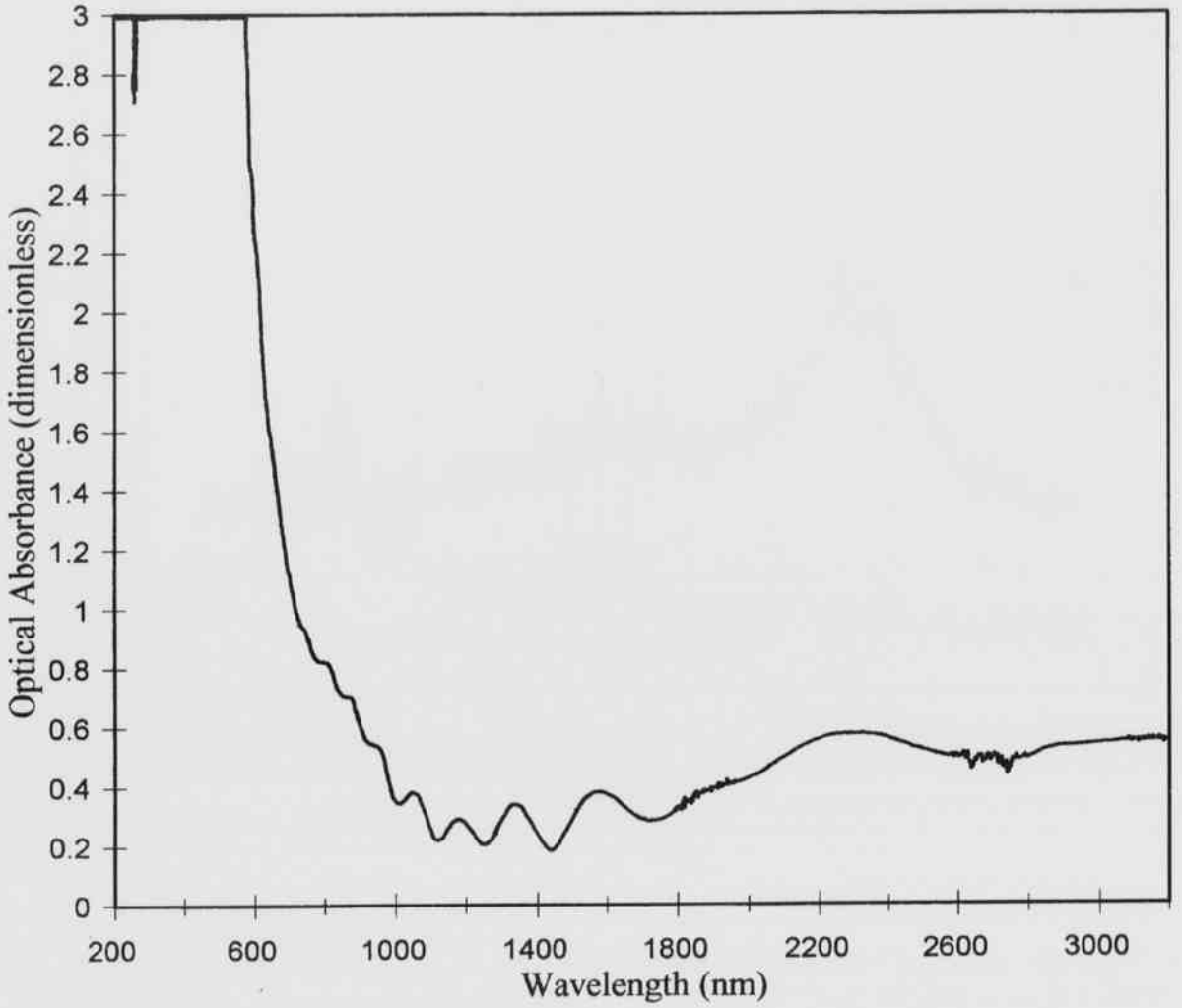

Fig. 4a. Optical absorbance versus wavelength spectrum for the same film as in Figure 3a. There is some "tailing" and "interference ripple" at wavelengths greater than 600 nm, near which the rapid rise in band-to-band absorbance begins.

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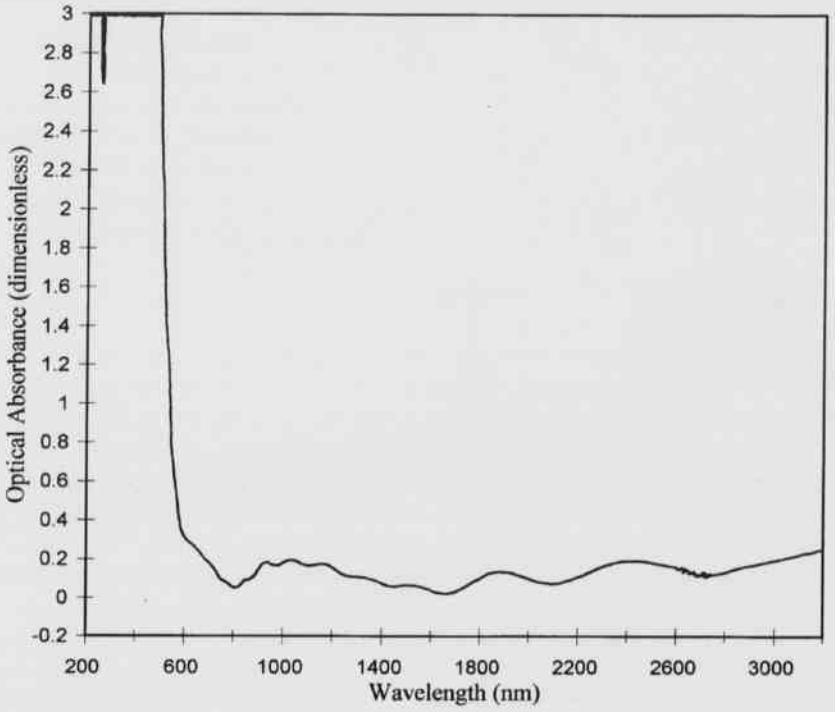

Fig. 4b. Optical absorbance versus wavelength spectrum for the same film as in Figure 3b. Again, note the rapid increase in absorbance near 600 nm consistent with the reported 2.0 eV.

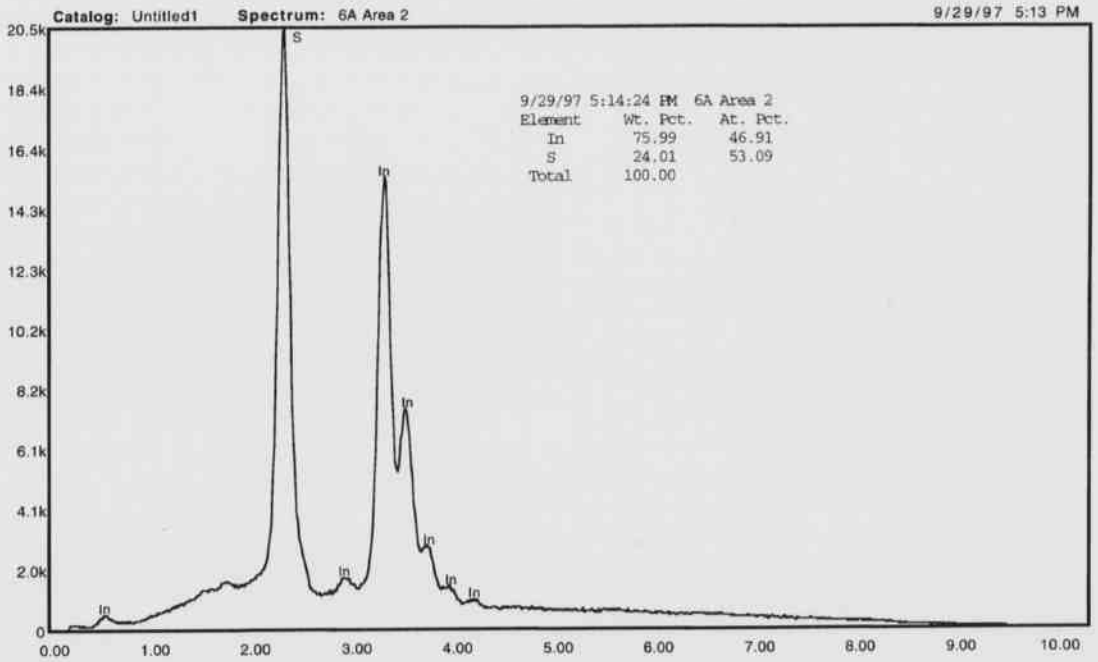

Fig. 5. Energy dispersive x-ray analysis (EDAX) data for a dark brown-orange (versus bright orange) indium sulfide film evaporated onto glass at 200°C. Note that the atomic percentages (≈ 47% In/53% S) indicate a film more indium rich than "pure" In_2S_3.

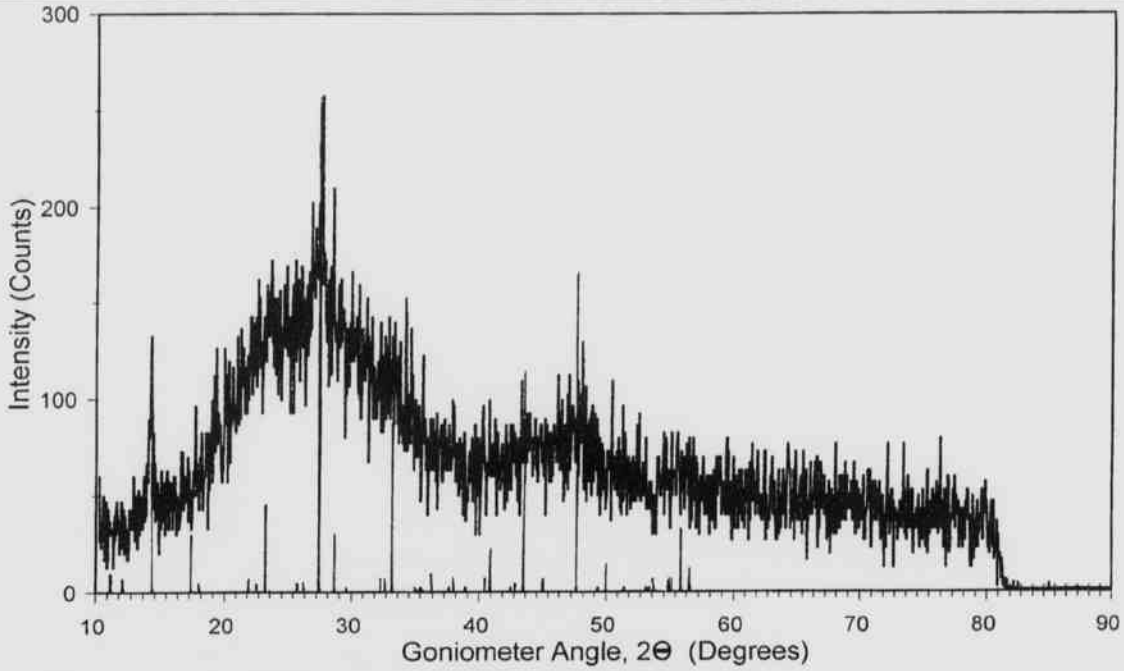

Fig. 6. X-ray diffraction spectrum for the film in Figure 5. Note that the only crystalline phase appearing is still In_2S_3, thus, implying an amorphous, indium-rich background matrix.

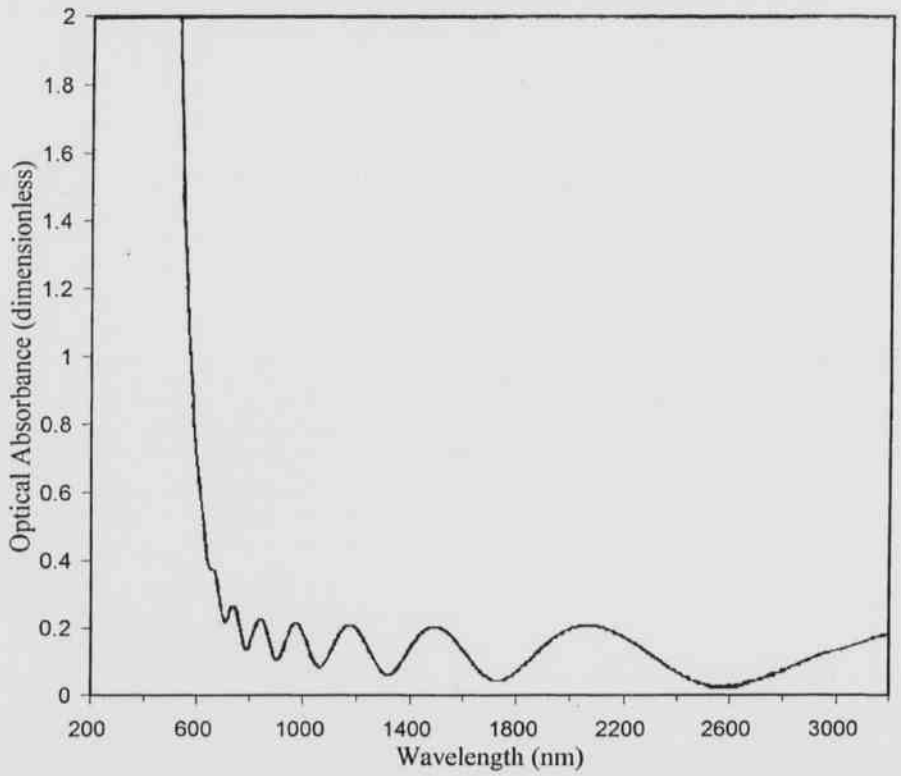

Fig. 7. Optical absorbance versus wavelength spectrum for the film in Figures 5 and 6. Note that the foot of the absorbance edge has been shifted from near 600 nm to over 700 nm, consistent with the darker color, and extensive bandtailing and/or a reduction in bandgap due to the excess indium.

A Methodology for Integrating Aerial Photography and LANDSAT TM Imagery for Inventory of Forest Land Cover

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Abstract

Forest cover for 7.25 million acres (2.93 million hectares) in southeastern Georgia was characterized for the years 1988 and 1994 with the intent of assessing the efficacy of remote sensing procedures for broad scale forest inventory. Landsat-5 Thematic Mapper digital satellite scenes of seven spectral bands were obtained for winter and summer of each year and were analyzed as two separate 14-band multi-temporal images. Images were geo-referenced to the universal transverse mercator (UTM) coordinate system prior to classification. Spectral classification with the ISOCLUSTER algorithm produced 250 categories. Color infrared aerial photographs were mapped to the digital imagery and were used to convert spectral categories to land cover features. For this study, land features of interest were limited to water, marsh, pine forest, hardwood forest, mixed pine/hardwood forest, urban, and where distinguishable, clearcut and agriculture. Accuracy assessment techniques indicated very good consistency.

Introduction

The practice of forest inventory is playing an increasingly important role in resource planning as demands for fiber increase upon finite resources. Traditional field inventory techniques are becoming harder to justify economically. In addition, the accuracy of field inventory is often less than optimal; surveys are usually less than one percent of area. Remote sensing techniques have the potential to make frequent, inexpensive, and useful inferences about very large areas. This manuscript reports on stage one of a two-stage project to characterize forest vegetation based on spectral signatures, i.e., reflectance of solar irradiance in specific narrow wavelengths, as a reasonably accurate map of major forest types. The purpose of this manuscript is to describe two aspects of the procedure: 1) the practical application of integrating aerial photography with industry standard digital image classification techniques for large areas; and 2) a method of assessing the accuracy of the resultant map.

The study area for this project, 7.25 million acres (2.93 million hectares) in southeastern Georgia (Fig. 1), was selected primarily because of the availability of detailed digital inventory data. In addition, the physiography of the region has several important features for remote sensing of forest vegetation.

(1) Negligible topographic variation exists. Shadows, various angles of light incidence, and spatial distortions inherent in high-relief areas are typically problematic in their effect on sunlight reflected from surface features, espe-

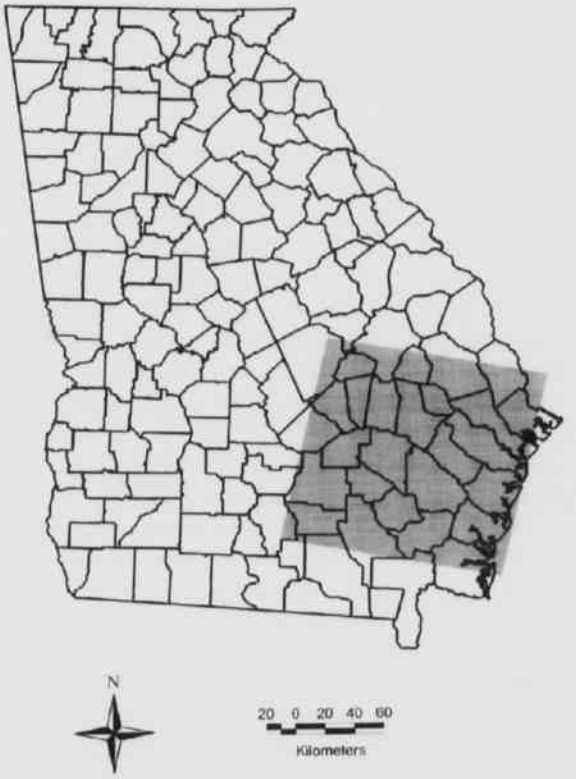

Fig. 1. Study area is in gray. Georgia counties are outlined in black.

cially forest vegetation which is typically highly variable.

(2) Large areas of managed pine forests are common. Because southern pines, particularly *Pinus taeda* and *P. elliotii*, figure prominently in North American supply of wood fiber, it is important that spectral signatures of various stages of pine plantations be adequately captured.

(3) Georgia ranks third among southeastern states in volume of sawtimber produced (FIA Homepage, 1997). Characterization of forest resources for a highly productive region of the southeastern United States has a greater value than for a less productive region.

Southeastern Georgia physiography is typified by slightly rolling hills to flat topography. Sandy soils in the area, though well drained, are usually low in fertility and this is a driving factor in the effort to improve wood fiber yields through genetic selection and intensive cultivation (Keefer, 1994). Agricultural crop production competes with forestry for land use in the western portion of the study area, but poorer soils in the east favor pines.

Because forest vegetation extent was of primary importance in this phase of the project, a limited set of land class features were selected for final categorization. These features are water, marsh, pine (*Pinus* spp.) forest, hardwood (deciduous species) forest, mixed pine/hardwood forest, urban/roads, and where possible to distinguish, clearcut and agriculture.

Materials and Methods

Data and Software.--Four dates of Landsat-5 Thematic Mapper (TM) digital imagery were selected based on their extent of significant cloud cover during dormant and peak growing seasons. The following image dates were used: February 26 and June 17, 1988; January 9 and May 17, 1994. All seven available spectral bands were acquired; they correspond to three visible bands, one near-infrared, two mid-infrared, and one thermal band (Lillesand and Kiefer, 1987).

Geometric correction of the images was performed on Arc/Info version 7.0 (from ESRI, Inc.) Image analysis was performed with ERDAS IMAGINE, version 8.2 (from ERDAS, Inc.). Both software packages operated on a Sun SPARCstation 20 workstation running Solaris 2.4. IMAGINE utilizes the ISOCLUSTER unsupervised classification algorithm. In addition, the software provides a very convenient graphical interface which facilitates the coding of spectral features. All digital maps were projected in the Universal Transverse Mercator coordinate system, Zone 17.

Aerial photographs were obtained from the U.S. Geological Survey National Aerial Photography Program (NAPP) for a subset of the study area, approximately 17%. Photographs were selected to correspond with the dates of the Landsat imagery. Due to the periodic latency in the flight schedule, color infrared photographs were available only for 1988. Only black and white panchromatic photographs were available for 1994.

Mitigation of Cloud Effects.--For this study, "significant" cloud cover denotes degradation of ground surface-reflected sunlight such that demarcation of ground feature categories is not feasible. Fortunately, only the summer-1994 image had any appreciable cloud cover. However, it was indeed significant; approximately 15% of the image was treated as cloudy.

Detection of the extent of clouds was facilitated by the use of the thermal infrared image band (commonly referred to as band 6). The cooler temperatures of the clouds contrasted distinctly with the ground surface features. Cloud temperatures registered as low pixel values in band 6. By plotting a histogram of these values, a breakpoint could be determined that represented the change from cloud to cool ground features such as water. Removing pixels having values lower than this threshold removed most of the cloud effect. Visual inspection of the remaining image indicated that the clouds were adequately removed. However, this left a portion of the image that could not be classified with winter and summer TM scenes together. To mitigate this problem, enclouded ground areas were extracted from the unclouded winter image and classified separately. The two separate classified images were later combined into a single image to complete the analysis.

Georeferencing.--Landsat images may be purchased in several degrees of geometric correction. Although the image vendor, Space Imaging EOSAT, will provide geometric correction to several map projections, the images often do not match features such as roads and waterways as effectively as when they are fit to a specific area. Therefore, geometric correction was the first step involved in preparing the images for analysis. In addition, the TM images were received with pixel resolutions of 25 x 25 m, and during the georeferencing operation they were converted to 30 x 30 m resolution through a process called nearest-neighbor resampling. This resampling process works by using the value of the pixel in the original image nearest to the relocated pixel coordinate as the new value. Compared to other methods that average nearby values, the nearest neighbor approach results in a blockier appearance but preserves the original sensor values without creating new values from averaging.

The method of georeferencing the four images used in this study was to match the first image to a standard base network (e.g., roads), then match the remaining images to the first corrected image. This image-to-image registration reduces potential errors that might be incurred if all images were referenced to the base network. The reason is that the base network is not part of the analysis procedure. Rather, it provides a standard for the first image, which then becomes the standard for the remaining images. If all images were

registered to the base network then, supposing a maximum error of one pixel, all images could be displaced from the base network equilaterally and the maximum error between all images would be two pixels. However, if all remaining images are registered to the first image, the maximum error is one pixel. In fact, localized errors can be substantially more than one pixel due to inaccuracies of the base network itself. In this study, the U.S. Geological Survey's 1:100,000 scale Digital Line Graph road network was used as the base network. Image to image registration was performed in IMAGINE.

Arc/Info provides a convenient interface for selecting corresponding points on the satellite image and a digital dataset, such as a road network. When a suitable number of correlated points have been selected, parameters for a first-order polynomial transformation are computed. The resulting equation is applied to affect three image characters-translation, scaling and rotation--that cause the image to match the known dataset, roads in this case. This highly interactive process can take several days to perform properly. Ideally, each pixel in each of the four images should correspond to the same spot on the ground. Of course, not all pixels will line up exactly. For this study, on average, image pixels were within one-half pixel width of their true location, i.e., RMS error in meters was 13.3 in the east-west direction and 13.1 in the north-south direction.

Classification.--Multispectral images are arrays of digital numbers (DN) representing surface reflectance of light in various wavelength bands. For example, the Landsat TM datasets are composed of seven coregistered images called bands. Each pixel location (e.g., row 1, column 1) contains a number from 0 to 255 (eight binary bits) representing reflectance of a particular narrow-band range of the light spectrum for a 25 x 25 m surface area. One feature of satellite imagery that is important to consider in image classification is the concept of a sensor's instantaneous field of view (IFOV). The IFOV is the surface area composing the light received by one sensor element or pixel. Note that IFOV defines the resolution of the image. The digital number representing the reflectance of a given pixel in the image is a weighted average of the respective reflectance of all features in the IFOV. Ideally, all pixels should fall completely upon a single feature, but in fact, many pixels capture light from several features, resulting in what is known as a mixed pixel. Mixed pixels contribute significantly to confusion between features when classifying digital imagery.

All spectral classifiers attempt to define spectral signatures of surface features. Spectral signatures are represented by the collection of DNs for different wavelengths associated with a surface feature. These values sometimes may be averaged or otherwise ciphered, and they sometimes may incorporate covariance between bands or between features. Generally, the signatures are considered to be multidimensional quantities.

Among standard spectral classifiers, two basic methods exist (Wilkie and Finn, 1996); supervised and unsupervised. The important difference is in the way spectral signatures are developed. Supervised methods require prior knowledge of the study area inasmuch as a human analyst selects known portions of the images from which to develop spectral signatures. In this case, a polygon may be digitized around a feature class causing, for example, 10 pixel locations to be acquired for that signature, resulting in 10 seven-dimension values. These polygons are called training areas because they are used to "train" the classification algorithm regarding that feature. By collecting several representative training statistics, the analyst hopes to characterize all such features over the extent of the image. Confidence values could then be applied to each pixel in the image according to its fit with the "known" spectral signature.

Unsupervised methods, on the other hand, attempt to designate signatures based on natural "clumpiness" of the spectral dataset. Consider Fig. 2 which depicts a hypothetical dataset of three bands, green, red, and infrared. Some features may be well defined, whereas others may be barely distinguishable. Still others may not readily fall into any conceivable class. Often, similar classes can be made distinct by including another spectral band. However, a drawback of unsupervised classification is that it produces only spectral classes; it does not produce feature classes. Consequently the analyst must investigate all output classes to determine their relation to feature classes. Furthermore, the burden of assigning confidence values lies completely with the analyst.

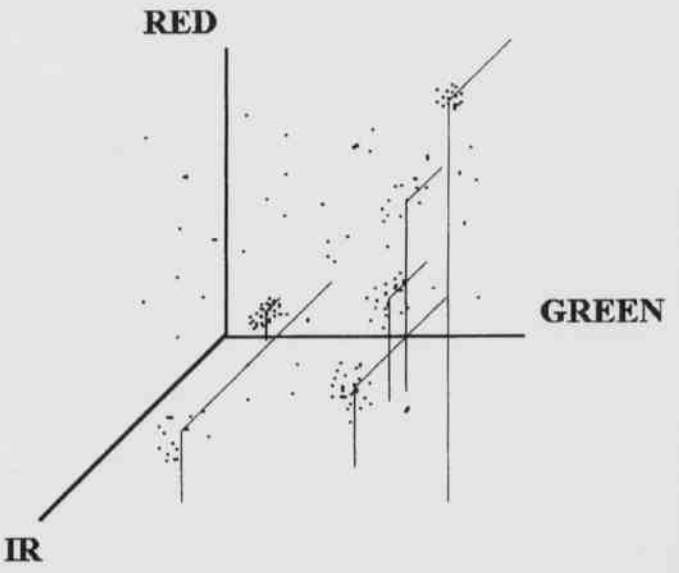

Fig. 2. Hypothetical clusters in three spectral bands. Lines are drawn to midpoints of clusters.

The IMAGINE software includes the ISODATA algorithm for unsupervised classification. A detailed explanation is included here to clarify the need for steps that follow. Execution of the program is controlled by several user-supplied parameters: maximum number of classes (NBINS), maximum number of iterations (MAXITER), and percent convergence threshold (CONV%). Assuming a seven band image, the operation of this algorithm is as follows (ERDAS, 1994).

1) Define NBINS classes evenly dividing the spectral space. Basically this means 255/NBINS for each band. These class values will change during execution of the program. Note that these class values would denote seven-value coordinates in spectral space.

2) Working through each pixel location in the image, compute the distance from each pixel's spectral coordinate to each NBINS value according to the modified Euclidean distance formula

$$D = \sqrt{\Sigma\ (d_i - C_i)^2}$$

where D = distance from segment i; i = band number from 1 to seven; d = digital number of band i; and C = class i from step 1. The pixel is temporarily assigned to the class having the shortest distance to the pixel. This step is repeated for all pixel locations in the image.

3) Collect all pixel values in each tentative class and average the pixels in each band. This becomes the new n-coordinate class value. Repeat this procedure for all classes; then begin step 2 again with the new class values.

4) During the iteration of steps 2 and 3, many pixels will change classes causing the means of the class values to change. The rate of change eventually slows, and the algorithm stops when either the number of classes denoted by CONV% no longer changes, or MAXITER has been reached.

When all the images in this study were transformed to the UTM (zone 17) coordinate system, the two images for each year were combined into a single file, one per year, to facilitate application of the algorithms. Thus, ISOCLUSTER was executed on one 14-band image for 1988 and 1994, respectively, and one seven band image for the enclouded area of the 1994 image. The computational procedure took five days per image on the SPARCstation 20 to create output images composed of 250 values. The enclouded area, representing only 15% of the study area, was processed with NBINS=50 due to time constraints. Recoding time is a function of NBINS, not area.

Obviously, this is many more classes than needed for the final map. However, two or more distinct features will sometimes occupy a class regardless of how many initial divisions are used. For example, swamp and marsh are often subject to this confusion due to the effect of surface water in the understory. This fact is less problematic with more classes than with fewer classes.

One can think of the output image as a reduction of practically an infinite number of potential classes (2^{8*14}-1) to NBINS classes, 250 in this case. Consequently, a given class will be scattered throughout the image, associated with whichever ground features happen to have similar reflectance. The feature coding process involves highlighting each class individually, verifying the associated ground feature, and recoding the numeric class to a descriptive class. The process of recoding a class requires the analyst to view as many of the given class's associated ground features as possible. This is why aerial photographs are so valuable. Actual ground visitation at a similar level of detail would be prohibitively expensive. However, some ground visitation is important to resolve ambiguities and spot check estimates from photos.

Integrating aerial photography for feature coding.--Ordinarily, field forays may supplement the use of aerial photography as ancillary information. However, due to the availability, quantity, timeliness, and low cost of color-infrared aerial photography versus the cost of trips to the study area, in this study nearly all feature coding was accomplished through aerial photographs. Some ground reconnaissance was performed prior to classification whereby the authors drove the highways of the study area and spot-checked a hardcopy of the satellite imagery. In addition, for this study, land managers substituted for detailed field forays in "reality checking" the final classifications.

To facilitate the time consuming task of finding on the aerial photograph the spot that corresponds with a point on the computer-displayed map, outlines of the aerial photos were digitized in a form that could be displayed against any of the images. Fortunately, IMAGINE allows a large number of image viewing screens to be displayed simultaneously. In addition, these viewers may be geographically referenced, such that information displayed in one viewer is accessible in other viewers. Therefore, a useful layout incorporates views of summer and winter TM images, the classified image, boundaries of aerial photographs, and any necessary magnifications of these constituents. Another feature of IMAGINE is that any given class can be displayed separately or highlighted. This makes it much easier to find a given pixel on the aerial photographs.

Ultimately, however, the task of verifying each of the classes is time consuming due to potential ambiguity within classes. Mixed pixels create the most difficult ambiguities because the pixel assumes spectral characteristics of several features and this can give it the appearance of something completely different. Note that a relatively high degree of proficiency in interpreting aerial photography is required since it is used so extensively.

Accuracy Assessment.--Errors in interpretation, incomplete data, or confusion of feature classes will result in errors in the final classified map. Therefore, some method of assessing accuracy must be implemented. The general prin-

ciple of accuracy assessment is to compare estimated feature values for pixels to known feature values for the same pixels. Normally, one cannot test every pixel so a percentage of pixels is sampled. Known feature values can be obtained in a number of ways, e.g., aerial photographs, ground visitation, expert knowledge, or other ancillary data. Aerial photographs can provide good reference data, but some pixels will be difficult to visually co-register.

Congalton (1988) noted several variations on simple random sampling, including stratifying based on land cover and stratifying geometrically, cluster sampling, and systematic unaligned sampling. He concluded, however, that the simple random sampling or stratification by land classes performed best for agriculture and forested areas in that study.

IMAGINE provides an interface for assessing the accuracy of classified images. The approach is similar to that recommended by Congalton (1988) because one can select simple random sampling, stratification based on class value, or equalized random sampling (i.e., each class is assigned an equal number of samples). In addition, one can define a minimum number of points per class, total number of sample points, and some degree of homogeneity of surrounding pixels via a "majority window. " This last issue is implemented by considering the pixels in a window of n x n pixels (where n is greater than two) surrounding the candidate sample. If the values of the pixels are the same for some user-defined threshold, then the candidate pixel is retained. The purpose of such a threshold is to control the number of pixels in areas of high diversity as such areas are more likely to contain misclassified pixels due to the larger number of mixed pixels.

Digital outlines of the photographs were used to eliminate areas of the classified image not actually verifiable. Thus a "clipped" image was created corresponding to the coverage of the aerial photographs and the accuracy assessment was performed on this subset (Figure 3). Table 1 presents the results for the accuracy assessment for the classifications of the 1988 and 1994 images, respectively. Generally, the classes for 1988 and 1994 are within 10 percentage points of each other, except for the water class. Apparently, the majority window restricted the number of possible samples in the already small population of inland water such that fringe pixels had a higher likelihood of being selected. This result warrants future attention.

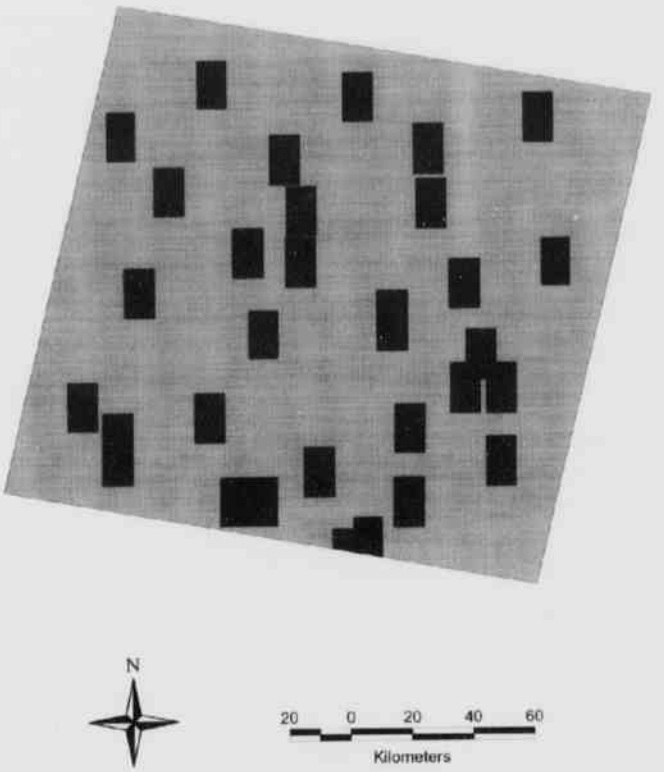

Fig. 3. Aerial photograph outlines (black) were used to delineate a subset of the study area (gray).

Discussion

Much theoretically oriented literature exists regarding the accuracy of spectral classification (Fenstermaker, 1994). However, a rigorous analysis of the classification accuracy was not attempted for this report. The purpose of the classification accuracy assessment as presented herein was to provide a meaningful indication as to the efficacy of the resultant map for later stages of this research. Notwithstanding, in the authors' experience (Weih et al., 1993; Thomasson et al., 1994), the percentages in Table 1 are very agreeable for such a large and diverse area. In addition, spot checks of the 1988 classification by personnel experienced with the area indicate similar agreement. Therefore, it appears that the use of aerial photography as a verification medium for unsupervised classification can be a viable alternative to more expensive field checking. Future research in this area could investigate specific combinations of spectral bands for efficiency in classifying various vegetation types, development of spectral curves for vegetation communities and individual species, and the practical application of theoretical accuracy assessment concepts to production-oriented image classification endeavors.

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Table 1. Percent of samples deemed correct from accuracy assessment.

	1988	1994
Water	30.9	100.0
Marsh	93.3	100.0
Pine Forest	90.7	89.6
Mixed Forest	54.4	67.7
Hardwood Forest	70.3	85.7
Urban/Roads	100.0	90.0

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Coplanarity Test for Selecting a Pair of Charged-Particle Tracks Resulting from a Single Neutral-Particle Decay

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Abstract

It is hard to determine directly the position of a neutral subatomic particle, but when such a particle decays into a pair of charged particles, it is easy to determine the positions of the charged decay particles and thereby infer the position of the parent particle at the time of its decay. A minimum of two coordinate points for each of the two decay particles is needed to reconstruct the position of the parent vertex. The mathematics of the reconstruction process is inherently interesting, and it can be used to demonstrate to students the utility of some of the most fundamental ideas of vector analysis.

Introduction

A mathematically interesting and physically significant problem arises in the effort to reconstruct the position (at decay) of a parent neutral-particle using position measurements of each of its (binary) charged-particle decay products. When a neutral particle decays into two charged products, momentum conservation assures a single plane contains these two products, the parent particle and the parent particle's point of origin (the collider vertex). Measurement of the paths for both charged products allows two independent determinations of the (x, y, z) position of the neutral particle's decay vertex.

One cross-product vector equation asserts the colinearity for each of the two emerging pairs (providing a total of six scalar equations). Neither vector equation, alone, can be used to solve for the decay vertex position (x, y, z), as the determinant of coefficients in each case is zero. This result is not surprising as two points will determine only the line along which the vertex lies, but not the (x, y, z) point itself.

Mixing pairs in the six scalar equations will provide two sets of three independent equations in x, y, and z. These equations allow two independent sets of vertex points to be calculated for any pair of charged particle products.

A test of common origin for each emerging charged particle pair is made possible using the coplanarity requirement for any particle pair created in the decay of the neutral parent particle, since these decay particles will emerge from a common point. Thus, coplanarity within a single decay makes possible grouping of product pairs as the two calculated (x, y, z) vertices will be the same within experimental errors.

Materials and Methods

It is hard to determine directly the position of a neutral subatomic particle, but when such a particle decays into a pair of charged particles, it is easy to determine the positions of the charged particles and thereby infer the spatial position of the parent particle at the time of its decay (Braithwaite and Braithwaite, 1995).

A minimum of two collinear points along each of two decay-particle pairs emerging from a parent vertex is needed to determine the (x, y, z) coordinates of the parent vertex. The two vector equations in Figure 1 and Figure 2 assert colinearity for each of two emerging pairs. Each yields three equations for x, y, z, but neither vector equation alone can be used to solve for the vertex point at (x, y, z), as the determinant of the coefficients in each case is zero. This result is expected as two points determine if a line along which (x, y, z) lies, but not a unique point. However, if these two sets of three equations are mixed together, the mixing procedure discussed below is able to provide two maximally-distant (x, y, z) vertex points from measured results.

If the charged particles had a common parent par-

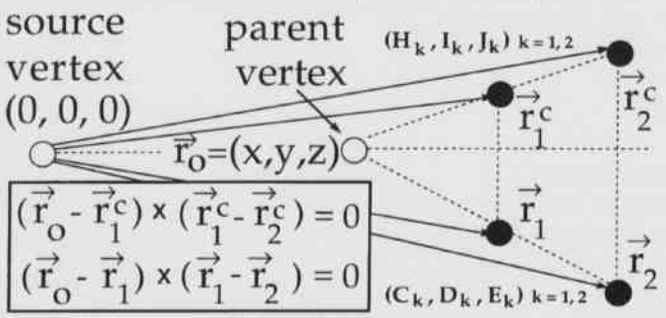

Fig. 1. Spatial relationships between parent and measured binary decay products.

2 parent vertices inferred for each decay into 2 products

First Colinear requirement:

$$\begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ x - H_1 & y - I_1 & z - J_1 \\ H_{12} & I_{12} & J_{12} \end{vmatrix} = 0 \Rightarrow$$

(4) $J_{12}(y - I_1) - I_{12}(z - J_1) = 0$

(5) $-J_{12}(x - C_1) + H_{12}(z - J_1) = 0$

(6) $I_{12}(x - C_1) - H_{12}(y - I_1) = 0$

$$\Rightarrow \begin{array}{l} (4)\quad 0\,x + J_{12}\,y - I_{12}\,z = J_{12}I_1 - I_{12}J_1 \\ (5)\quad -J_{12}\,x + 0\,y + H_{12}\,z = -J_{12}H_1 + H_{12}J_1 \\ (6)\quad I_{12}\,x - H_{12}\,y + 0\,z = I_{12}H_1 - H_{12}I_1 \end{array} \quad \text{and:} \begin{vmatrix} 0 & J_{12} & -I_{12} \\ -J_{12} & 0 & H_{12} \\ I_{12} & -H_{12} & 0 \end{vmatrix} \equiv 0$$

Determinant(coefficient matrix) = 0 is not surprising as the direction of each (product) track determines a line along which parent vertex (x, y, z) falls, but not a unique point.

Second Colinear requirement:

$$\begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ x - C_1 & y - D_1 & z - E_1 \\ C_{12} & D_{12} & E_{12} \end{vmatrix} = 0 \Rightarrow$$

(1) $E_{12}(y - D_1) - D_{12}(z - E_1) = 0$

(2) $-E_{12}(x - C_1) + C_{12}(z - E_1) = 0$

(3) $D_{12}(x - C_1) - C_{12}(y - D_1) = 0$

$$\Rightarrow \begin{array}{l} (1)\quad 0\,x + E_{12}\,y - D_{12}\,z = E_{12}D_1 - D_{12}E_1 \\ (2)\quad -E_{12}\,x + 0\,y + C_{12}\,z = -E_{12}C_1 + C_{12}E_1 \\ (3)\quad D_{12}\,x - C_{12}\,y + 0\,z = D_{12}C_1 - C_{12}D_1 \end{array} \quad \text{but:} \begin{vmatrix} 0 & E_{12} & -D_{12} \\ -E_{12} & 0 & C_{12} \\ D_{12} & -C_{12} & 0 \end{vmatrix} \equiv 0$$

Mixing component equation pairs (⇐ two colinear requirements) ⇒ 2 sets of (x, y, z). Find: y and z using (1) and (4), x and y using (2) and (5), x and z using (3) and (6).

Fig. 2. Six equations for calculating two values for the (x, y, z) vertex of each parent.

ticle, the distance between the two calculated vertex values would have to be nearly zero. A non-zero value for this distance would be expected due to experimental error.

Each of the six equations given in Figure 2 actively involve just two of the three variables, each being the equation of a plane perpendicular to one of the coordinate planes. By extracting the three pairs of planes that involve the same two variables, e.g., x and y, each such pair of planes can easily be solved for values of the two variables it involves. Assuming that there is some experimental error present, this process leads to two distinct values of each variable as candidates for the parent particle's position when it decayed. These three pairs of coordinate values correspond to the eight potential parent point positions. Each of these potential parent point positions is a vertex of a rectangular box with sides parallel to the coordinate planes.

For convenience we consider the pair of potential parent vertex points corresponding to selecting the smaller choice for each coordinate value for the first point and the larger choice for each coordinate value for the second point. These two points are the vertices of the box nearest and farthest from the origin, respectively, and hence are endpoints of a diagonal of the box. Thus, the distance between these two points is a measure of the size of the rectangular box which in turn is a measure of how far the lines are away from being collinear. If the distance is relatively small, the two decay particles presumably came from a common parent particle from within the rectangular box. Whereas, if the distance is relatively large, the two decay particles presumably came from different parent particles.

Note that in working with the three pairs of planes involving the same two variables, we can simplify our work considerably. For concreteness, let's walk through the process in the case in which the pair of planes involve the x and y variables only. In this case the pair of planes are perpendicular to the xy-plane and the value of z is arbitrary. This problem may be viewed as a problem involving only the lines of intersection of the pair of planes with the xy-plane. Thus, the problem reduces to the two-dimensional problem of finding the intersection of a pair of lines in the xy-plane.

Since Cramer's rule is most useful in solving two linear equations in two unknowns, it can be used to automate the solution of our problem. In the rare case in which these two lines in the xy-plane are parallel, we can either ignore the pair of particles, or we can use any of a variety of two-dimensional computations to easily find the distance, d, between the two lines and hence the distance between the original pair of planes.

Of course in this rare case, the other two pairs of equations give two values for z but only one value for each of x and y. The size of the sum of distances, d, and the absolute value of the difference of the two z-values could be used in place of the diagonal in the general case when none of the pairs of planes are parallel. Similar reasoning applies to each pair of planes involving just two variables. Thus the process considered here permits us in each case to move away from three-dimensional geometry and computations into the much more familiar and less complicated two-dimensional setting of the corresponding coordinate planes.

Results and Discussion

Figure 3 is a schematic of one-half of a microTPC, a small, cylindrical 4-plane Time Projection Chamber

(Weiman et al., 1995; Burks et al., 1997), designed for determining the collider vertex position with precision by tracking charged-particles (Byrd et al., 1995) emerging from the center of the composite STAR Detector (STAR, 1992) at RHIC, the Relativistic Heavy Ion Collider under construc-

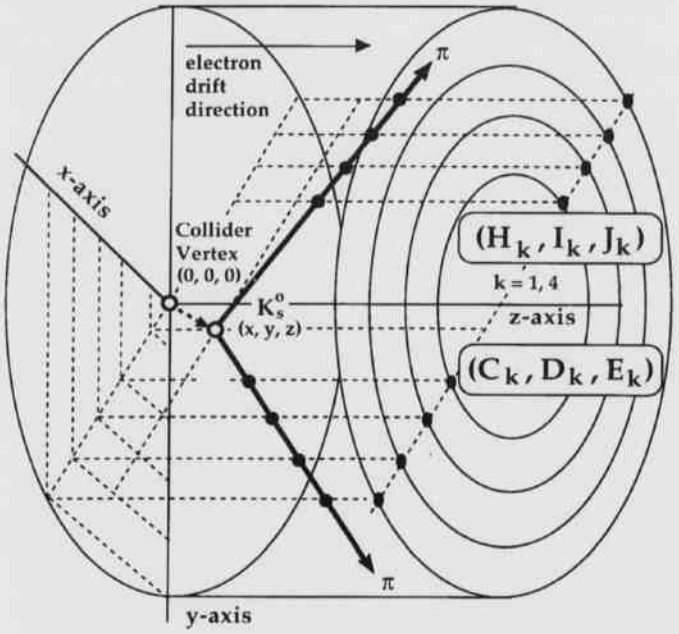

Fig. 3. One-side of the microTPC intended for use as STAR's vertex tracker. The microTPC gives 4 points for each charged pion from a parent $K^o \rightarrow \pi^+ + \pi^-$.

tion at Brookhaven National Laboratory.

Increased strange-quark production is one of the signatures of a quark-gluon plasma predicted in the aftermath of a ultra-relativistic nucleus-nucleus collision (Harris and Müller, 1996). Since each kaon is singly strange, and since hundreds of kaons are produced in each central nucleus-nucleus collision, measuring kaon production is tantamount to measuring strangeness production (Byrd and Braithwaite, 1996).

Differences in energy-loss (versus momentum) are not sufficient to be used to separate charged kaons from charged pions in the microTPC. Thus, a new method is needed for measuring strangeness production using the microTPC. This new method is the determination of the number of neutral kaons, as proposed below.

Figure 4 shows a top and side view of GEANT (1994) simulations of four pairs of charged decay particles each pair of which came from a common parent decay particle position. The microTPC is quite small so magnetic field effects on trajectories of the charged particles, although included in the simulation, are correspondingly small.

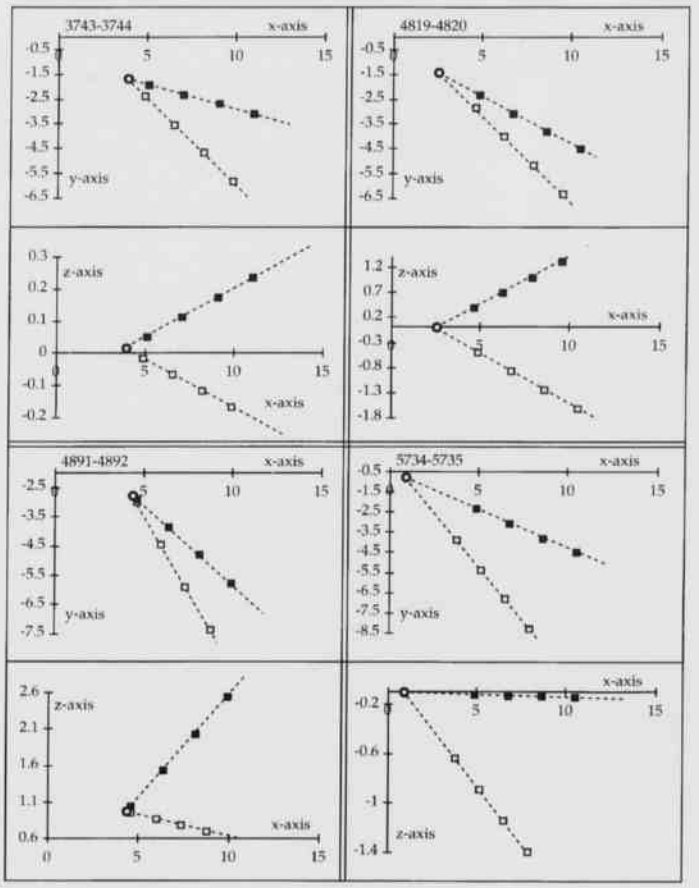

Fig. 4. Four Monte Carlo generated samples showing each average parent vertex inferred two sets of measured decay-product positions: top and side view.

This magnetic field arises because the composite STAR Detector features an axially symmetric solenoidal magnetic field. This magnetic field was designed for use in determinating the momentum of charged particles within the much larger Main TPC, located outside and concentric to the microTPC.

The observation of fairly straight-line tracks in Fig. 4 supports the idea that the microTPC is small enough so that curvature due to the magnetic fields is negligible for grouping charged pion pairs from neutral kaon decay. Negligible bending means we would expect essentially the same parent decay particle position rectangle regardless of which two positions we used for each charged decay particle.

When more than two pixel points are available to determine the direction of each pion, the problem of associating pixels with an individual pion may be uncoupled from the present method of finding the parent (neutral kaon) vertex using the two decay product directions. However, little additional information is available by using the additional pixels

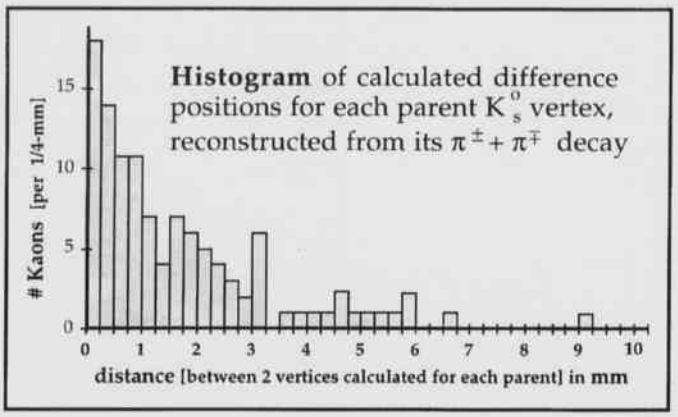

Fig. 5. Simulation showing clustering of two values for (x, y, z) for each parent.

as was determined using a rough-set grouping algorithm (Clark et al., 1995), so the present method of identifying pion tracks as "children of a common mother" is economical and sufficient for measuring strangeness production in STAR.

Figure 5 shows a histogram of a simulation of over 100 decays of neutral parent kaons into pairs of charged pions within STAR's microTPC. As expected, the calculated distance between the two potential parent kaon positions is seen to be relatively small when the pairs of daughter pion particles originate from a common parent kaon.

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Separating $K^{\pm}$ from $\pi^{\pm}$ using In-Flight Decays to $\mu^{\pm} + \nu$

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Abstract

A method is presented for completely distinguishing between charged kaons and charged pions by using their charged muon (plus neutrino) decays (with neutrinos undetected) for meson laboratory momenta up to 1000 MeV/c. When either a charged kaon or a charged pion decays into a muon and a neutrino, momentum-energy (four-momentum) conservation will be used to provide unique "kinematic trajectories" for distinguishing kaon decays from pion decays when the change in three-momentum of the muon from that of either parent kaon or pion is measured (or simulated). In a magnetic field, observation of a tracked particle showing a "kink" and/or a change in helicity indicates the decay of the parent particle into a similarly-charged muon product. Unique kinematic separation between each parent kaon and parent pion is possible for each parent particle's momentum up to 1000 MeV/c. Curvature-radius of the helical path in a magnetic field is used to determine each charged particle's momentum, whether it be a kaon, a pion or a muon. A weak field is adequate for making this determination since momentum (curvature radius) need only be measured to an accuracy of about 10%. Monte Carlo calculations of the kinematic trajectories have been carried out for primary meson momenta between 0 and 1000 MeV/c and for a range of emission angles (or "kinks") between 0° and 180°. Monte Carlo results from these in-flight decay kinematic calculations show a complete separation is possible for pion decays from kaon decays for laboratory momenta up to 1000 MeV/c because these two classes of meson decays cluster into completely separated 2-D regions of difference-momentum ⊗ muon-angle space. The most difficult region for separating primary particles occurs for small-kink decays within less than 5°. Decay halflife and time dilation require an efficient time projection chamber to be fairly large, because kaons are strongly favored over pions at the higher laboratory momenta and for the smaller time projection chamber geometries.

Introduction

The present work provides the foundation for success for two distinct and different research efforts. (1) Mapping a Time Projection Chamber (TPC) for acceptance and efficiency as a function of position within the TPC will be seen as possible now using the present method of identifying charged pions from charged kaons within a large TPC (Sauli, 1987). (2) Measuring the strangeness production occurring in each central collision between two ultra-relativistic nuclei is made possible by counting the total number of charged kaons decaying within the TPC, as kaon production will be seen to provide a direct measure of strangeness production. This latter effort complements measurements of neutral kaon decay within a microTPC designed to be the component detector located closest to the collider vertex for ultra-relativistic nucleus-nucleus collisions (Braithwaite and Braithwaite, 1997).

The feasibility of detecting charged kaons was studied using the kink pattern and/or change in helicity-radius of a track (Howe et al., 1995) associated with each secondary muon formed in $K^{\pm} \rightarrow \mu^{\pm} + \nu$ decay. This kaon decay has a 63.51% branching ratio as opposed to and distinguished from secondary muons formed in the following pion decay: $\pi^{\pm} \rightarrow \mu^{\pm} + \nu$, which has a 99.99% branching ratio (in neither case is the neutrino detected).

"Kinematic trajectories" for these decays cluster into completely separated 2-D regions of difference-momentum ⊗ muon-angle space, or $\Delta P \equiv |P_o - P_\mu| \cdot \text{sign}(P_o - P_\mu)$ versus θ_μ, showing kinematic separation is possible between charged kaon decays and charged pion decays. This complete kinematic separation is attributed to the much larger breakup momentum, 235.5 MeV/c in the center of momentum frame, available to each of the binary decay species (muon and neutrino) in the process of $K^{\pm} \rightarrow \mu^{\pm} + \nu$ decay. In contrast, a much smaller breakup momentum, 29.8 MeV/c in the center of momentum frame, is available to each of the binary decay species (muon and neutrino) in the process of $\pi^{\pm} \rightarrow \mu^{\pm} + \nu$ decay.

A fully-relativistic kinematics program (Braithwaite, 1972) was used to calculate each outgoing muon momentum arising from the spontaneous in-flight decay of either type of parent meson into a muon and a neutrino.

This study will demonstrate how easy it is to effect separation between the muon decay products coming from kaons and pions using kinematics alone, and thus it will establish the feasibility of using muon decays of charged pions and/or charged kaons in determining the acceptance

and efficiency of a large Time Projection Chamber (TPC) like the Main TPC of the STAR (Solenoidal Tracker) instrument at the Relativistic Heavy Ion Collider (Climer et al., 1996).

Pions dominate the charged particle production following a central Au on Au event at the Relativistic Heavy Ion Collider (RHIC). Kaons only occur between 5% and 10% as frequently, thus, any method proposing to extract the kaon decays must separate them completely from the pion decays if these decays are to be uniquely identifiable as coming from kaons rather than pions in a sea of background pions.

Materials and Methods

Above 500 MeV/c, charged kaons and charged pions interact with the gas in a large TPC to produce fairly similar ionization track densities, as a result track density is of little use in distinguishing kaon tracks from pion tracks. A limited but unique signature is possible for identifying kaons from pions if we examine the subset of kaons and pions that decay into muons before leaving the TPC.

In fact, since track densities for kaons, pions and muons are all quite similar within a TPC, kaons are only easily distinguished from pions at the point of spontaneous in-flight decay of each meson to a muon plus a neutrino. At the point of decay a "kink" occurs and the helicity of the track changes, as the laboratory momentum of the outgoing charged muon will be different from that of the parent meson. The meson particle-parentage may be determined by comparing the change in the track's helicity-radius (momentum) with the full spectrum of calculated kinematic trajectories of the muons produced in these decays. 99.99% of charged pions decay by $\pi^{\pm} \rightarrow \mu^{\pm} + \nu$; thus, before considering the detection of charged kaons from the kink pattern and the track helicity-change associated with each $K^{\pm} \rightarrow \mu^{\pm} + \nu$ decay (a 63.51% branching ratio), contributions from pion contamination must be shown to be negligible.

A fully-relativistic kinematics program (Braithwaite, 1972), originally written in FORTRAN, was modified to accommodate an EXCEL spread-sheet Monte Carlo calculation of the spontaneous in-flight decay of either type of parent meson into a muon and a neutrino. The "target" particle in an in-flight decay is non-existent, so both its rest mass and kinetic energy were taken as zero. This simplified the formalism somewhat, facilitating the calculation enough to make a spread-sheet approach practical. For each value of momentum for each meson species, laboratory-momentum branches (as applicable) were calculated for the outgoing muon from each decaying meson species.

Using the spread sheet method above, kinematic trajectories have been calculated for the in-flight decays of both pions and kaons for laboratory momenta up to 1000 MeV/c over the complete range of laboratory muon angles between 0° and 180°. 4000 Monte Carlo events were used to vary randomly the relativistic three-momentum for each pion and kaon between 0 and 1000 MeV/c. Equally spaced muon angles were chosen when calculating outgoing muon momentum associated with each parent kaon and parent pion.

The difference between the initial momentum of kaons or pions and the final momentum of the decaying muon is easy to determine experimentally (to better than 10%) using an externally-imposed (weak) magnetic field. To facilitate separation a graph of momentum difference versus laboratory angle was generated, giving predicted "kinematic trajectories" which are unique for each type of parent meson.

Results and Discussion

Figure 1 shows a distinct separation between "kinematic trajectories" for kaon decays from that for pion decays, except at muon angles of less than 5°. This graph shows that decaying pions may be separated uniquely from decaying kaons by comparing the momenta of initial and final charged particles at muon angles greater than 5°, where a "kink" in the charged-particle track has a chance of being noticeable.

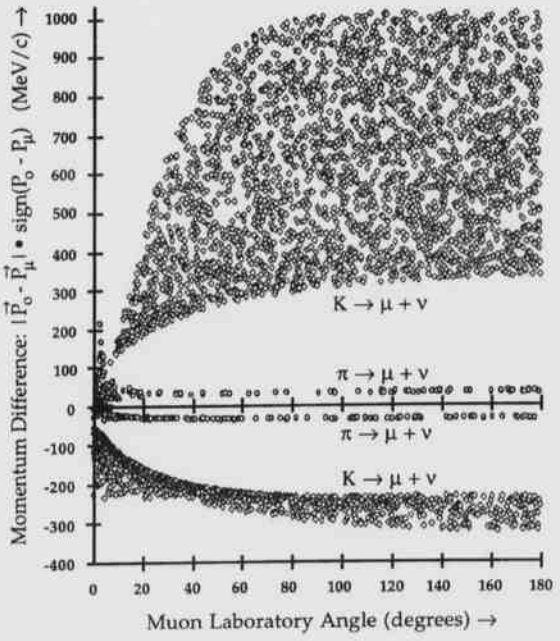

Fig. 1. "Kinematic trajectories" using the measureable $\Delta P \equiv |P_o - P_\mu| \bullet \text{sign}(P_o - P_\mu)$ show kaon decays cluster into completely separated 2-D regions of $\Delta P \otimes \theta_\mu$ space from pion decays. MC events for $\theta_\mu < 10^o$ need further examination.

To investigate the separation of muons from parent kaons versus muons from parent pions in the less well resolved angular region (of each forward-going muon) using "kinematic trajectories" alone, in-flight decay kinematics were examined (in a similar manner). 4000 Monte Carlo events were used to provide the laboratory three-momentum for each outgoing meson while restricting the muon laboratory angles to values between 0° and 15° (the less well resolved angular region). Figure 2 shows the results of focusing an additional 4000 Monte Carlo events into this forward angular region. Good separation between incident pions and kaons is seen for all laboratory momentum values for the parent mesons up to 1000 MeV/c.

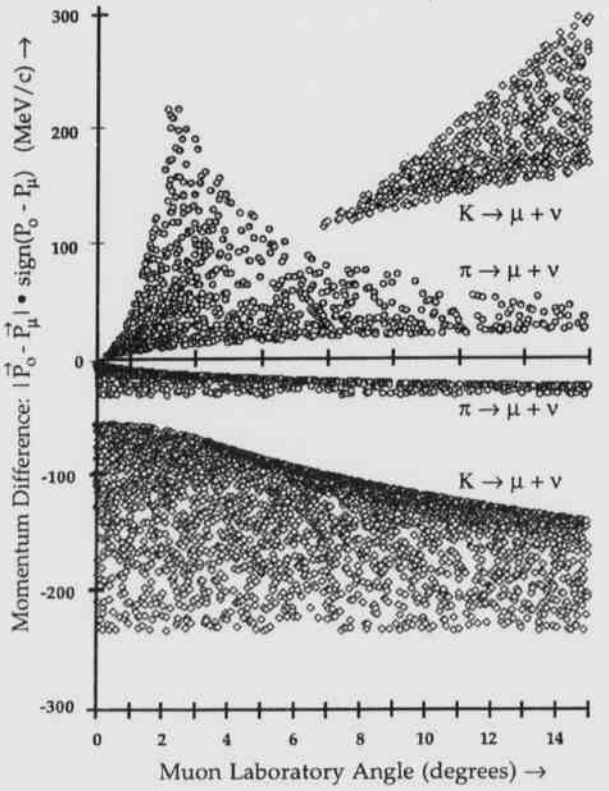

Fig. 2. 4000 Monte Carlo events between 0° and 15° show good separation of kaon decays from pion decays in this less well resolved angular region.

Much above 1000 MeV/c, the use of "kinematic trajectories" alone fails to effect separation between parent kaons from parent pions at the most forward angles. However, at muon-emission angles larger than 5°, the separation between decaying kaons and pions remains complete. Also, it is worth noting that few kaons or pions are produced at laboratory momenta above 1000 MeV/c. In addition, due to time dilation, those few pions produced above 1000 MeV/c will have their effective lifetimes (in the laboratory) increased dramatically compared to that of the kaons, therefore, pions (with laboratory momenta greater than 1000 MeV/c) will be considerably less likely to decay within the active volume of even a large TPC.

For example, at a laboratory momentum of 1000 MeV/c, a charged pion ($\tau = 26.03$ nanoseconds, or $c\tau = 7.804$ meters) will have a relativistic factor of $\gamma_\pi = 7.23$ (which is its time dilation factor). Thus in the laboratory the *effective* $c\tau = 56.42$ meters. If we take the geometry of the Main TPC of STAR (with an inner diameter of 2 meters and an outer diameter of 4 meters), the fraction of charged pions at 1000 MeV/c decaying within the Main TPC is $\exp(-1m/56.42m) - \exp(-2m/56.42m) = 0.0173$ or about 1 in 60.

In contrast, at a laboratory momentum of 1000 MeV/c, a charged kaon ($\tau = 12.37$ nanoseconds, or $c\tau = 3.7$ meters) will have a relativistic factor of $\gamma_K = 2.259$ (also its time dilation factor). Thus in the laboratory the effective $c\tau = 8.358$ meters. If we again take the geometry of the Main TPC of STAR, the fraction of charged kaons at 1000 MeV/c decaying within the Main TPC is $\exp(-1m/8.358m) - \exp(-2m/8.358m) = 0.100$ or about 10%. Thus, at this high momentum, kaons are favored over pions by about a factor of 6. Despite a smaller kaon branching ratio, time dilation brings up the ratio of kaon decays to pion decays within the Main TPC to between 20% and 40%, which is much closer to parity.

Now that a complete separation in particle-parentage is possible by associating a simulated or a measured meson decay with a unique "kinematic trajectory," the next step is the mapping of the TPC using either kaons or pions. Any realistic simulation of this TPC mapping requires a charged-particle transport program that takes into account interactions within the detector as well as motions of the particles within the relevant magnetic fields. The Monte Carlo program GEANT (1994) is capable of carrying out this particle-transport, and GEANT is available to members of the STAR Experiment at RHIC from the Center for European Nuclear Research in Geneva, Switzerland (CERN).

Now that mapping the acceptance and efficiency of STAR's Main TPC (with either kaons or pions) is seen to be possible, the second research effort, namely sampling kaon production, is seen to be possible as well. These two research efforts are now feasible, as it has been established that using "kinematic trajectories" alone it is possible to distinguish charged kaon decays from charged pion decays. The momentum changes need to be measured associated with the kink patterns in the charged-particle tracks and the associated change in the helicity-radius (momentum) of these tracks associated with the respective muon decays in

the reactions: $K^{\pm} \rightarrow \mu^{\pm} + \nu$ and $\pi^{\pm} \rightarrow \mu^{\pm} + \nu$.

Increased strange-quark production is one of the signatures that a Quark-Gluon Plasma was created in the aftermath of an ultra-relativistic nucleus-nucleus collision as predicted by the Standard Model (Harris and Müller, 1996). Thus the second research effort, namely sampling kaon production for comparison purposes between different primary collider events, is physically interesting for the substantial number of kaon events expected to occur for each primary ultra-relativistic nucleus-nucleus collision. Measuring an increase in singly-strange kaon production in the aftermath of each central Au-Au collision is tantamount to measuring an increase in strangeness production, one of the signatures of the onset of a Quark-Gluon Plasma.

Examining kinks and/or radius of curvature changes in a charged-particle track in order to determine into which pattern of in-flight decay kinematics the parent meson resolves itself allows the mapping of the acceptance and efficiency of the Main Time Projection Chamber of STAR using either meson species. Simulating the decays of either or both meson species is facilitated using the *generating* tables called *TAS Tables* which are derived from CERN's Monte Carlo program GEANT and provided to its users by the STAR Collaboration (Olson, 1993). These tables provide all the transport and kinematic information necessary for a TPC acceptance and efficiency study.

The output from these TAS Tables may be used to generate simulated pixel data for use in examining and critically testing the tracking algorithms (Howe, 1995) used to establish the charged-particle momenta, before and after the "kink." Whether obtained from real pixel data or from simulated pixel data, the momentum change and the angle change make possible the classification of each "kink" event into either a parent kaon or a parent pion using the present work.

As discussed earlier, the charged kaon lifetime is less than half the charged pion lifetime. Thus the kaon is more likely to decay within even a large TPC than is the pion. In addition, the charged kaon rest mass of 493.65 MeV/c^2 is substantially larger than the charged pion rest mass of 139.57 MeV/c^2, resulting in a substantially smaller time dilation for kaons than for pions at the same laboratory momentum (less than 1000 MeV/c).

Neglecting time dilation, a rough estimate of the number of kaons decaying within STAR's Main TPC is $\exp(-1m/3.7m) - \exp(-2m/3.7\ m)$ or about 1/5 of (~2/3 of) the total number of charged kaons being produced, which is roughly 40-60 kaons per primary collider event. At a laboratory momentum of 1000 MeV/c, the time-dilation factor for charged kaons is $\gamma_K = 2.26$, less than 1/3 of the time-dilation factor for charged pions that is $\gamma_\pi = 7.23$ (see the earlier discussion). In addition to its smaller (rest-frame) lifetime, the smaller time dilation factor for the kaon additionally favors its decay over pion decay within the TPC, thus bringing the populations of decaying kaons and decaying pions within STAR's Main TPC into a more even balance.

TAS tables mentioned above are accessible to any user familiar with general purpose programming using event-based data-processing. Statistical accuracy in any Monte Carlo simulation of TPC acceptance and efficiency may be improved by aggregating the results of several primary 200*A GeV Gold-on-Gold collisions, in which each Gold nucleus has a kinetic energy of 19,600 GeV in the laboratory. Aggregating charged meson production from several primary Au-Au events increases the number of charged kaons (or pions) traveling through the TPC, improving the calibration accuracy. For normalization purposes, the *average* number of kaon (or pion) decays into muons within the TPC may determined for each primary event.

In summary, the present work provides the foundation for success for two distinct and different research efforts. Mapping a Time Projection Chamber (TPC) for acceptance and efficiency as a function of position within the TPC is possible now using the present method of identifying decaying charged pions from decaying charged kaons within a large TPC. Also, because the two classes of meson decays cluster into completely separated 2-D regions of difference-momentum $\otimes$ muon-angle space using the measurable $\Delta P \equiv |P_o - P_\mu| \cdot \mathrm{sign}(P_o - P_\mu)$ versus θ_μ, measuring strangeness production in each central collision between two ultra-relativistic nuclei is possible now by separating kaon decays (from pion decays) by identifying the appropriate "kinematic trajectory" for the decaying meson, then counting the total number of charged kaons decaying within the TPC. This method has merit as singly-strange kaon production is known to provide a direct measure of strangeness production. All other strange hadrons are produced in numbers too small to provide any hope of choosing one central collision over another by using them to measure strangeness production.

ACKNOWLEDGMENTS.—This research was supported, in part, by the U. S. Department of Energy through Grant DE-FG05-92ER-40753. The first author wishes to thank Miss Amber Climer, a Donaghey Scholar at UALR, and Dr. Iwona Sakrejda, a permanent Staff Member of Lawrence Berkeley National Laboratory, for their suggestion of using the decays of charged kaons as a vehicle for separating kaons from pions in order to carry out an acceptance and efficiency study for the detection of K^+ and K^- within the Main Time Projection Chamber of STAR. This idea developed over one fall semester and two summer semesters while Amber was being supported at LBNL on three separate Lawrence Berkeley National Laboratory Undergraduate Research Fellowships, awarded competitively by LBNL's Center for Science and Engineering Education.

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The Effect of Media Constituents on In Vitro Culturing of Cowpea (*Vigna unguiculata*) Shoot Tip and Leaf Disk Explants

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Abstract

Cowpea is an important legume food crop that is commonly grown in Arkansas and numerous other southern states. The application of biotechnological approaches for the improvement of U.S. cowpea genotypes is currently not possible due to the lack of a regeneration and transformation system. Therefore, the first priority of our research efforts is the development of a plant regeneration system that will facilitate plant transformation studies. In an effort to optimize the media requirements for tissue culturing cowpea, we evaluated the in vitro response of shoot tip and leaf disk explants to various levels of Murashige and Skoog (MS) macro and micro nutrients, vitamins, and iron. One commercial cultivar, Early Scarlet (formerly 91-135), and one advanced Arkansas breeding line, 91-245, were used as tissue sources. Shoot tips were cultured on media augmented with 5 mg/L kinetin and 0.01 mg/L naphthaleneacetic acid (NAA). Multiple shoots were produced from shoot tips, and these grew well when cultured on full strength MS. However, increasing MS levels to 1.5 times the standard concentration induced taller shoots from both genotypes. Leaf disks were cultured on MS media supplemented with 0.5 mg/L benzylaminopurine (BAP) and 1 mg/L 2,4dichlorophenoxyacetic acid (2,4-D). Callus proliferation was greatest on media containing full strength MS supplemented with 0.5 mg/L BAP and 1 mg/L 2,4-D. The effects of the media constituents were genotype dependent, with Early Scarlet generally producing larger shoots and greater amounts of calli. The results obtained from this study demonstrate that the plant genotype and growth hormones have the greatest influence on cowpea growth in vitro. Therefore, in developing a cowpea regeneration system, it will be necessary to test numerous genotypes in combination with various growth regulators. To improve regeneration frequencies the media components can be optimized for the genotypes of interest.

Introduction

Cowpea, or southernpea [*Vigna unguiculata* L. (Walp.)], is a drought-tolerant grain legume that constitutes a source of dietary protein in Africa, Brazil, India, and the USA. Commercial cowpea growing areas are found in numerous states, such as Arkansas, California, Georgia, Louisiana, Mississippi, Missouri, and Texas. Constraints to U.S. production include the lack of both drought tolerance and resistance to pests and diseases. Cowpea stunt, a viral disease caused by the synergistic interaction of cucumber mosaic virus (CMV) and blackeye cowpea mosaic virus (BlCMV) can cause devastating economic losses to local farmers (Anderson et al., 1996). Unfortunately, good sources of resistance to both of these stunt viruses have not been found within the domesticated species. Therefore, the availability of a regeneration and transformation system would provide a means for producing transgenic virus resistant cowpea.

Effective molecular genetic manipulations require a reliable method of plant regeneration. However, tissue culture studies on cowpea have shown it to be highly recalcitrant, and attempts to regenerate plants from in vitro-cultured explants have not been very successful (Latunde-Dada, 1990; Morginski and Kartha, 1984). In general, the culture medium plays an important role in the ability of the explant to regenerate shoots, with the specific medium requirements being highly dependent on the plant species (Dougall, 1981; Pierik, 1993). Therefore, we initiated this study to help us understand the media requirements for cowpea, which will aid us in our efforts to regenerate cowpea.

The long-term goal of our research is to develop a system in which biotechnological approaches can be utilized efficiently to introduce agronomically important genes into local cowpea breeding lines and commercial cultivars. Ultimately techniques such as these may help breeders produce cultivars that can overcome losses due to drought, pests and diseases. The objective of this study was to identify media that would be optimal for cowpea growth in vitro using 1) the response of shoot tip explants of two cowpea genotypes to various levels of Murashige and Skoog (MS) basal salts, iron, and vitamins and 2) the callusing response of leaf disk explants of two genotypes with two auxins and various levels of MS, iron, and vitamins.

Materials and Methods

Disinfection and Culture Establishment. (Shoot tips).--Two cowpea genotypes, the commercial cultivar Early Scarlet (formerly breeding line 91-135) and the advanced breeding line 91-245, were used in this study. Seeds were surface sterilized in 70% ethanol for 1 min and then shaken for 15 min on a gyratory shaker at 100 rpm in 1.6% w/v sodium hypochlorite (30% v/v Clorox, commercial bleach) containing 3 drops of Tween 20 (Sigma Chem. Co., St. Louis) per 100 ml Clorox solution. Seeds were then cultured individually on germination medium. Shoot apices, 5 mm long, of 7-day-old seedlings were isolated and placed on culture initiation medium in 25xl50-mm tubes. Shoot tips were placed vertically on the culture medium with approximately 1 mm of the cut end inserted into the medium.

Leaf Disks.--Trifoliate leaves from 11-day-old greenhouse-grown plants, Early Scarlet and 91-245, were removed and surface sterilized in 70% ethanol for 30 s, followed by immersion in a 20% Clorox solution for 10 min. The leaves were rinsed 4 times in sterile distilled water, cut into disks using a cork borer, and cultured with the abaxial side in contact with the medium.

Culture Medium and Conditions.--The basal culture medium, which served as a reference or standard medium throughout this study, consisted of MS (Murashige and Skoog, 1962) salts supplemented with 0.2 mg/liter thymine, 80 mg/liter casein hydrolysate, 3% sucrose, 0.8% agar [Agar-agar/Gum agar] (Sigma), and the vitamins 100 mg/liter *myo*-inositol, 1 mg/liter thiamine-HCl, 1 mg/liter nicotinic acid, 1 mg/liter pyridoxine-HCl and 2 mg/liter glycine. MS macro and micro nutrients at levels of 0.25, 0.5, 0.75, 1, and 1.5, vitamins at 0.5, 1, 1.5, and 2, and ferric-EDTA at 0.5, 1, and 1.5 times the standard concentrations were tested. The shoot tip culture medium consisted of variations of the standard medium supplemented with 5 mg/liter furfurylaminopurine (kinetin) and 0.01 mg/liter naphthaleneacetic acid (NAA). The leaf disk callus induction medium was composed of variations of the standard medium augmented with 0.5 mg/liter benzylaminopurine (BAP) combined with 2,4-dichlorophenoxyacetic acid (2,4-D) or NAA at 1 mg/liter. The media were adjusted to pH 5.8 with 1*M*KOH, dispensed in 25xl50-mm culture tubes (15 ml per tube), and autoclaved at 121° C and $1x10^5$ Pa (1.1 kg cm^{-2}) for 15 min. Shoot tip cultures were maintained at 12-h photoperiods of cool-white fluorescent light and 23±2°C, whereas, leaf disks were maintained under continuous dark conditions and 23±2°C.

Statistical Analysis.--This study consisted of six experiments, each with 9 replications per treatment. The first three experiments utilized shoot tips as explants and were set up as a two factor factorial, the two factors consisting of genotypes (Early Scarlet and 91 -245) and one of the three media components (MS, iron, or vitamins). After three weeks, data were recorded on height of shoots (cm), number of leaves per explant, number of shoots per explant, and the size of the largest leaf (cm). The second three experiments utilized leaf disks as explants and were set up as a three-factor factorial. The factors were genotype (Early Scarlet and 91-245), hormone type (NAA or 2,4-D), and one of the three media components (MS, iron, or vitamins). After a culture period of 3 weeks, data were taken on callus mass (g).

Data were subjected to an analysis of variance for a completely randomized design. Trend analysis was done in which the variation due to rates was partitioned into linear, quadratic, and cubic sources of variation. The linear source is the average change in the response as the medium concentration increases; quadratic and cubic sources measure degrees of departure from a straightline response. Statistical significance of any of these trend components indicates that the true response means differ with all medium concentrations. If the linear source is the only significant trend component, then a straight line is the pattern of response to increasing medium levels; if the non-linear sources are also significant, then the change in response is dependent upon the medium concentration. Mean separation was done by a T-test and significance was determined at the 5% significance level.

Results and Discussion

Effect of MS Major and Minor Nutrients on Shoot Tip Growth.--Varying the concentration of the MS macro and micro nutrients in the culture medium influenced the in vitro growth of shoot tips, with the responses differing between genotypes. There were significant linear and quadratic effects on shoot height for Early Scarlet and 91-245. Increasing MS levels up to 1.5 times the standard concentration resulted in taller shoots for both cowpea lines (Fig. 1A). However, Early Scarlet produced significantly taller shoots than 91-245 at all MS levels. Miller and Murashige (1976) also reported an increase in shoot height of foliage plants when the MS nutrients were increased over that normally provided in the medium. Interestingly, Early Scarlet shoot tips that were cultured with 1.5 MS also produced roots (Fig. 2). Since maximum shoot height for both lines was achieved with the highest MS level, 1.5 times the standard concentration, a further increase in the MS level may also further stimulate shoot growth.

Statistical analysis of data indicated a linear and quadratic significance for the number of leaves per explant with both Early Scarlet and 91-245. Increasing the MS level from one quarter to the standard concentration yielded the maximum number of leaves, 10 per explant, for Early Scarlet (Fig. I B). A similar significant increase in the number of

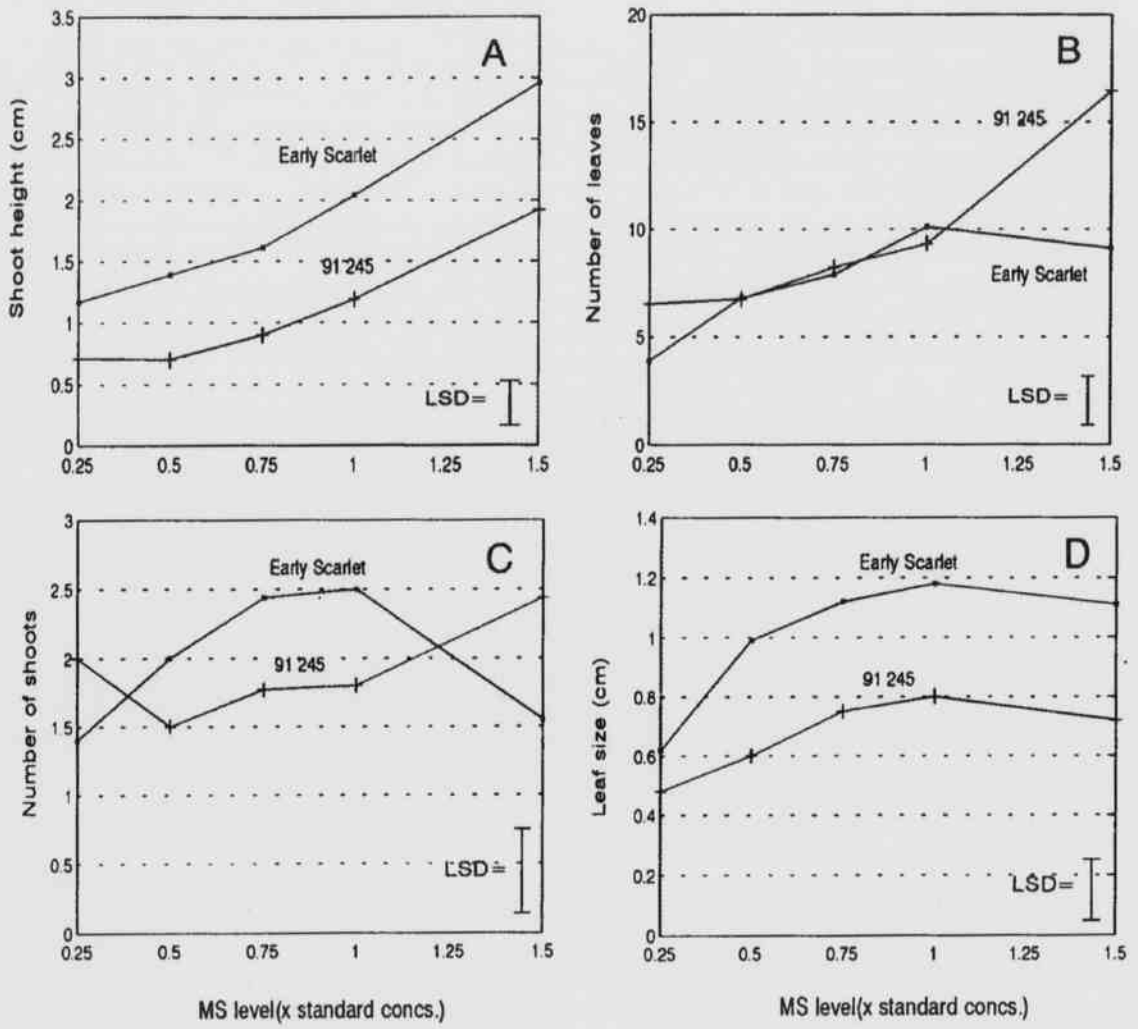

Fig. 1. Effect of MS levels on A) shoot height, B) number of leaves per explant, C) number of shoots, and D) size of the largest leaf for cowpea shoot tips derived from genotypes Early Scarlet and 91-245.

leaves produced was also observed for 91-245. However, unlike Early Scarlet, a further increase in the MS level, up to 1.5 times the standard concentration, resulted in an increase from 9 to 17 leaves per explant for 91-245.

There was a significant quadratic effect for the number of shoots per explant with Early Scarlet, whereas, both the linear and quadratic effects were significant for 91-245. Similar numbers of shoots were produced from explants cultured on media containing MS levels of 0.5, 0.75, and 1 times the standard concentration, however, with 1.5 MS the explants produced more shoots (Fig. 1C). The maximum number of shoots for Early Scarlet was obtained for shoot tips cultured on full strength MS.

The size of the largest leaf was linearly and quadratically significant for both genotypes. Maximum leaf sizes for both Early Scarlet and 91-245 were obtained with full strength MS (Fig. 1D). At this MS level, Early Scarlet produced significantly larger leaves than 91-245.

Effect of Iron on Shoot Tip Growth.--The linear response was significant for the height of shoots for both Early Scarlet and 91-245. Increasing the iron level in the medium reduced the shoot height for both Early Scarlet and 91-245 (Fig. 3). However, Early Scarlet produced taller shoots for each iron level. The number of leaves, number of

The Effect of Media Constituents on In Vitro Culturing of Cowpea (*Vigna unguiculata*) Shoot Tip and Leaf Disk Explants

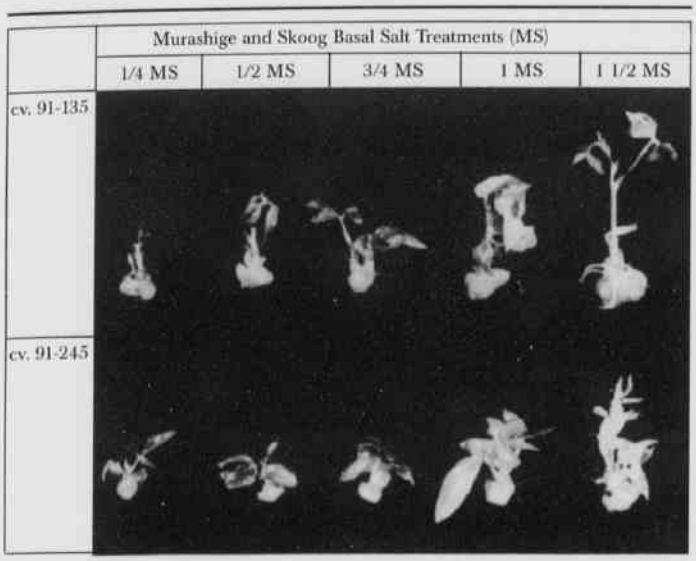

Fig. 2. Effect of MS levels on in vitro shoot growth of cowpea genotypes Early Scarlet (formerly breeding line 91-135) and 91-245.

shoots, and the size of leaves were not significantly influenced by the level of iron in the medium. However, leaf yellowing was observed with shoot tips cultured on medium containing 0.5 ferric-EDTA, indicating a deficiency of iron.

Effect of Vitamins on Shoot Tip Growth.--Varying the vitamin level in the medium produced no significant effect on shoot height or leaf size. The cowpea line Early Scarlet, however, produced taller shoots (mean = 2.76 cm) (Fig. 4) and larger leaves (mean = 1.16 cm) than 91-245 (shoot height mean = 1.42 cm; leaf size mean = 0.81 cm).

The cultivar by treatment interaction was significant for the number of leaves produced per explant. Increasing the level of vitamins resulted in an increase in the number of leaves for Early Scarlet (Fig. 5A). In 91-245 the maximum number of leaves per explant was achieved with a vitamin level of 1.5.

Increasing the level of vitamins in the medium had no significant effect on shoot multiplication for Early Scarlet. When vitamin levels were varied (Fig. 5B), data analysis revealed a significant linear and quadratic response on number of shoots produced per explant for 91-245. Increasing

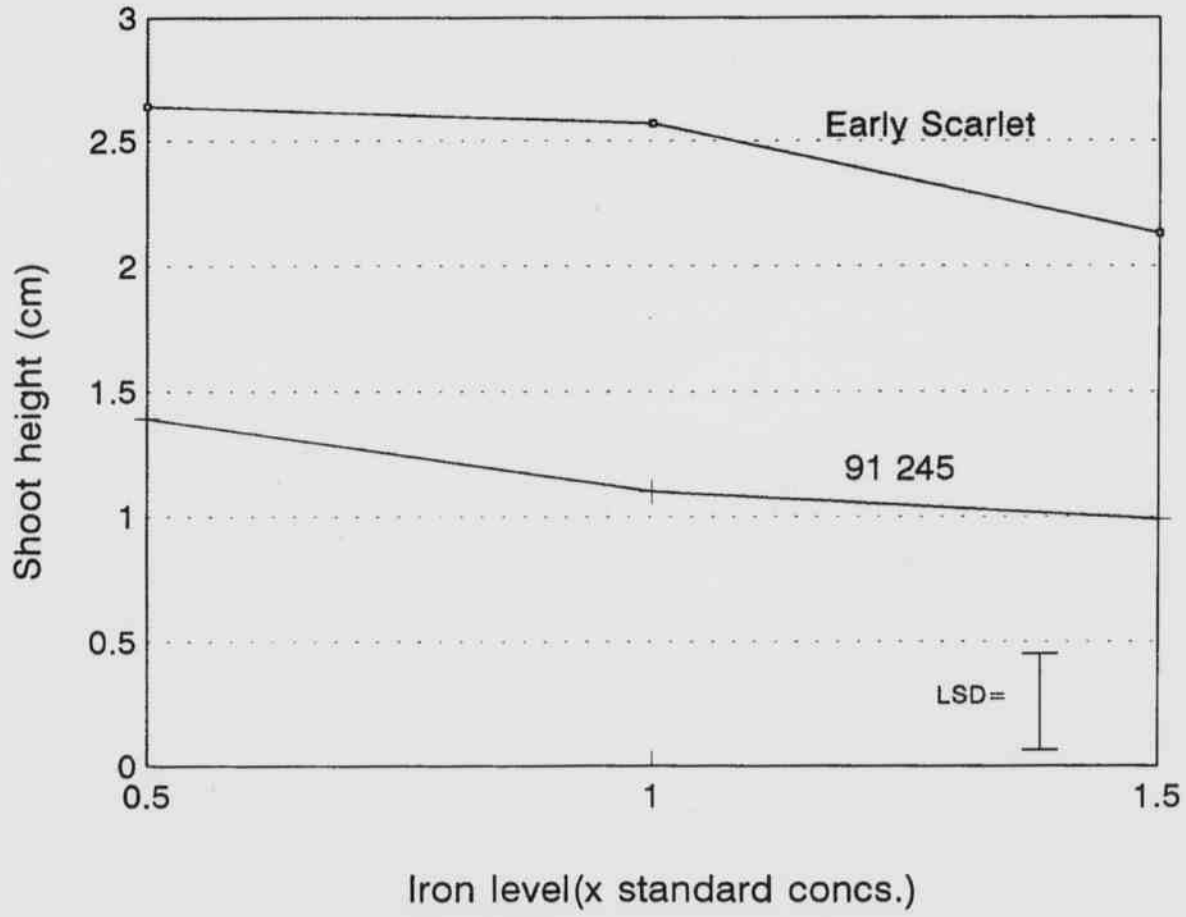

Fig. 3. Effect of ferric-EDTA on shoot height of cowpea shoot tips, Early Scarlet and 91 -245.

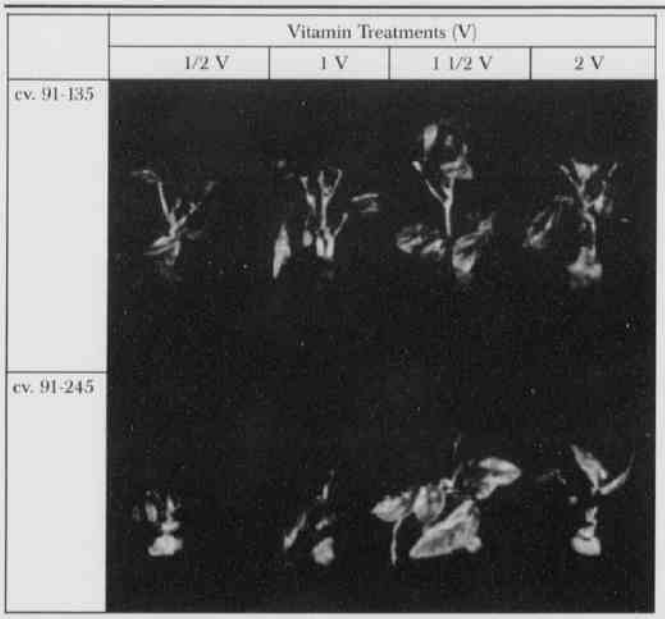

Fig. 4. Effect of vitamin levels on shoot tip culture of cowpea genotypes Early Scarlet (formerly breeding line 91-135) and 91-245.

the level of vitamins in the medium significantly increased the number of shoots produced.

Effect of MS Macro and Micro Nutrients on Callus Induction.--The amount of callus produced from leaf disk explants was influenced by the MS level, auxin type, and genotype. There was a significant linear and quadratic responses for callogenesis using both Early Scarlet with 2,4-D or NAA, and 91-245 with 2,4-D or NAA. Increasing the MS level in the medium resulted in greater callus growth to a maximum with full strength MS, regardless of auxin type or genotype (Fig. 6). Increasing the MS level from full to one and a half strength inhibited callus growth. At full strength MS, media augmented with the auxin 2,4-D stimulated greater callus growth than media containing NAA in both Early Scarlet and 91-245. On media containing all levels of MS, except 1.5 times the standard concentration, Early Scarlet produced more callus than 91-245, regardless of the type of auxin present in the media. The auxin NAA stimulated rhizogenesis; whereas, 2,4-D inhibited the production of roots in all treatments (Fig. 7). The superiority of NAA over 2,4-D in stimulating rhizogenesis was also reported for cowpea cv. Georgia-21 (Brar et al., 1997).

Effect of Vitamins on Callus Induction.--There was a significant cultivar by hormone interaction for callus induction from leaf disks. The greatest amount of callus was produced with leaf disks from Early Scarlet cultured on media

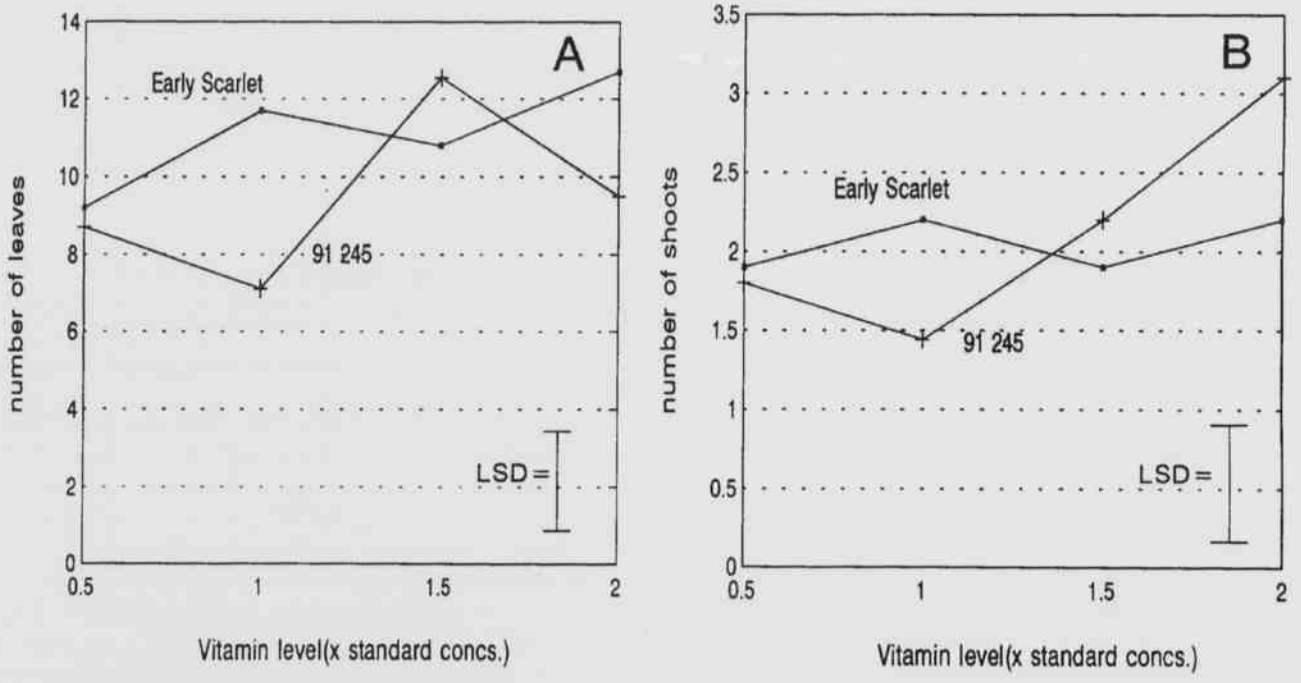

Fig. 5. Effect of vitamin levels on the A) number of leaves and B) number of shoots, produced from shoot tip culture of two cowpea genotypes, Early Scarlet and 91-245.

The Effect of Media Constituents on In Vitro Culturing of Cowpea (*Vigna unguiculata*) Shoot Tip and Leaf Disk Explants

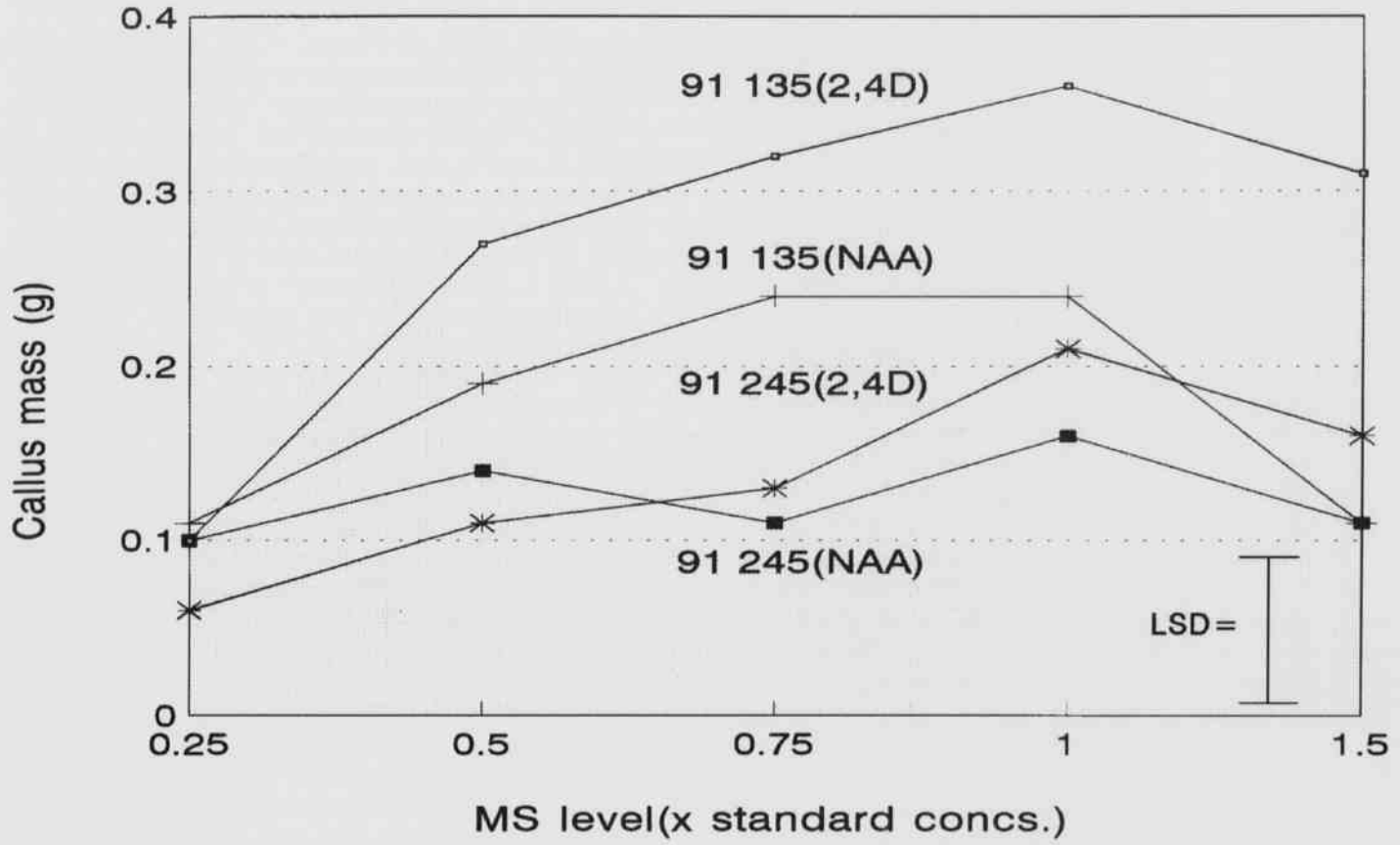

Fig. 6. Effect of MS levels, auxin type (2,4-D or NAA), and genotype (Early Scarlet or 91245) on callus induction of cowpea leaf disk explants.

Table 1. Effect of auxin type (2,4-D or NAA) and genotype (Early Scarlet or 91-245) on callus induction of cowpea leaf disk explants.

Plant Genotype	Auxin	Callus Mass (g)
Early Scarlet	2,4-D	0.30[a]
	NAA	0.20[b]
91-245	2,4-D	0.13[c]
	NAA	0.16[bc]

supplemented with 2,4-D (Table 1). In fact, Early Scarlet leaf disks produced greater amounts of callus than those of 91-245, regardless of the auxin type. The level of vitamins in the medium did not significantly affect callus growth (data not shown). Matsubara (1975) tested the effects of numerous vitamins on callogenesis of cowpea and found that there was no effect on growth except with the vitamin nicotinic acid,

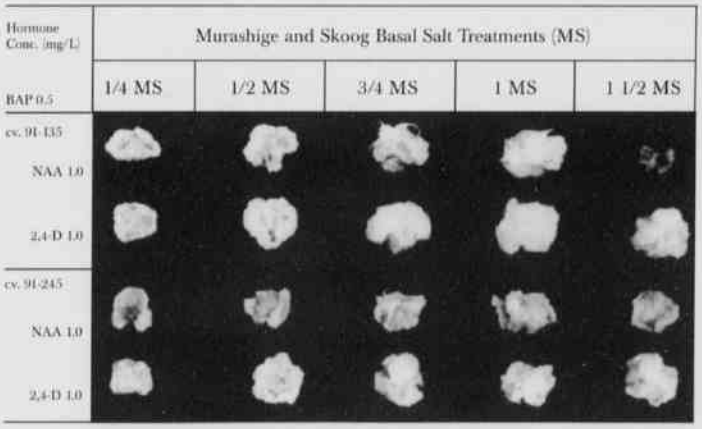

Fig. 7. Callogenesis of cowpea, cv. Early Scarlet (formerly breeding line 91-135) and 91-245, leaf disk explants after 3 weeks in culture with various levels of MS and two auxin types (2,4-D or NAA).

which increased callus production for the cultivar Akadane Onaga.

Effect of Iron on Callus Induction.--Genotype had a significant influence on callus induction, whereas auxin type or the level of iron had no significant effect. Overall, Early Scarlet produced a greater amount of callus (mean = 0.27 g) than 91-245 (callus mean = 0.15 g) (data not shown).

The genetic make-up of a plant has been shown to have perhaps the greatest influence on the in vitro growth of plants (Pierik, 1993; Finer, 1994). Data presented in this study verifies that the plant genotype is the single most important factor influencing the growth of cowpea shoot tip and leaf disk explants. This genotype specific response has also been documented in *Vigna radiata* (Gulati and Jaiwal, 1990) and *Vigna aconitifolia* (Eapen and Gill, 1986).

Conclusions

Plant genotype exhibited a major influence on growth of cowpea explants cultured in vitro. The cultivar Early Scarlet displayed greater growth of shoot tips and greater callus proliferation from leaf disks than 91-245 in these experiments. In our study, full strength MS provided good growth from shoot tips for both cultivars. However, increasing the MS level to 1.5 times the standard concentration induced taller shoots for both of these cowpea genotypes. At this level of MS other growth factors may also be increased dependent on the plant genotype. Iron content of the medium did not have a major effect on quantitative growth of cultured shoot tips, but symptoms of iron deficiency were visible with low levels of iron. Varying the vitamin level in the medium also did not have a significant effect on shoot tip growth or callus induction. When utilizing leaf disk explants, the standard concentration of MS is optimal for callus induction with these two genotypes and with both hormones. This study demonstrates that genotype and hormones have the greatest effect on the in vitro responses of cowpea. Therefore, in regeneration studies on U.S. cowpea cultivars, it will be critical to test numerous genotypes and to carefully evaluate different hormones and hormone concentrations. In addition, the results presented here suggest that media components can affect the growth response of cowpea. Optimization of media components will likely be necessary for different cultivars in order to increase regeneration and transformation rates.

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A Comparison of Waterbird Utilization of Two Northwest Arkansas Reservoirs

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Abstract

Waterbird use of two moderately-sized reservoirs in northwest Arkansas was studied in the autumns of 1993 and 1995. In addition to waterbird counts; surface area, water temperature, conductivity, pH, turbidity, dissolved oxygen, macrophyte presences, number of total macroinvertebrates and degree of human activity were evaluated. Lake Fayetteville supported a greater overall waterbird species richness and species abundance than Lake Wedington. The observed number of ducks per hectare showed a significant difference between the lakes in both 1993 and 1995. Surface feeding birds were significantly more abundant at Lake Fayetteville in both 1993 and 1995, whereas diving birds, which feed on fish and invertebrates, showed no significant difference between the two lakes. Water temperature, pH, turbidity, and dissolved oxygen were not significantly different, but conductivity was consistently higher in Lake Fayetteville. However, total biomass for standing crop of macrophytes was higher for Lake Wedington. The number of macroinvertebrates at various depths was slightly higher for Lake Wedington, and human activity due to boating and fishing was not significantly different between the two lakes. Many characteristics may influence waterbird abundance of these lakes, but siltation of Lake Fayetteville is occurring at a faster rate than Lake Wedington. This has resulted in extensive shallow areas which probably enhances availability of food for surface feeding birds at Lake Fayetteville.

Introduction

Some waterbirds, especially waterfowl, have been declining throughout North America. Six major duck species have declined since the U.S. Fish and Wildlife Service started keeping records in 1955 (Low, 1987). However, recent surveys of waterfowl populations have shown an increase in most waterfowl numbers (Young, 1995). This increase is probably due to protection of wetlands plus relatively high amounts of rainfall in key waterfowl breeding areas of Canada and the northern United States. Clearing of wetlands once used by migrating and overwintering waterfowl throughout the United States has concentrated waterfowl in fewer wetlands, thus increasing the potential for predation and disease. Many reservoirs have been constructed throughout the United States, and some of these attract diverse species of waterbirds with high abundance while others do not (Kadlek, 1962). Research is needed to determine habitat features important to waterbirds so that construction and management of reservoirs can be improved for waterbirds use.

Many physical, chemical, and biological properties have been investigated in relation to waterfowl and waterbird utilization of rivers, creeks, lakes, and ponds. Most studies investigate spring breeding periods where no single characteristic seemed to be associated with high or low use. Water quality properties do not seem to have a direct affect on waterbird use, but they do structure the aquatic community in which waterbirds feed (Begon et al., 1990). Waterbirds are diverse in habitat selection (White and James, 1978). This selection is probably due to diverse means of foraging behavior, such as wading, dabbling, and diving (Bent, 1866-1954; Ehrlich et al., 1988). Lake morphology is an important characteristic in habitat selection by breeding waterfowl, especially lake size (Mulhern et al., 1985; Godin and Joyner, 1981). Larger wetlands can support a greater number of breeding pairs of waterfowl (MacArthur and Wilson, 1967; Godin and Joyner, 1981; Lillie and Evrard, 1994) and higher species composition (Connor and McCoy, 1979; Suter, 1994). Research by several workers (Mack and Flake, 1980; Hoyer and Canfield, 1990; Suter, 1994) suggest that lake characteristics have limited influence on overwintering waterfowl numbers. Suter (1994) states food availability is probably the main factor affecting lake selection by overwintering waterfowl, but the effects of differing levels of macrophytes and invertebrates on waterfowl are not clear. Mack and Flake (1980) showed that invertebrate numbers and taxa were correlated with waterfowl use,

whereas macrophytes abundance had no influence. Other studies suggested that invertebrates and macrophytes have no affect on overwintering waterfowl numbers (Murkin and Kadlec, 1986; Hoyer and Canfield, 1990).

We had two main objectives. The first was to determine waterbird species composition and relative abundance in two northwestern Arkansas reservoirs. The second was to evaluate the relationship between site characteristics, water quality, macrophyte abundance, macroinvertebrate abundance, human activities, and waterbird use of the two lakes. The term waterbird includes all birds observed using the two reservoirs during the survey periods and includes the following avian orders: Anseriformes, Charadriiformes, Ciconiiformes, Coraciiformes, Gaviiformes, Gruiformes, Pelecaniformes, and Podicipediformes.

Study Site.--Research was conducted at two reservoirs in northwestern Arkansas, Lake Fayetteville (T. 17N, R. 30W, Sec. 24) and Lake Wedington (T. 16N, R. 32W, Sec 3). Lake Fayetteville, constructed in 1949-1950, is located north of Fayetteville, Arkansas. At the time of impoundment, the lake had a surface area of 69 ha, a maximum depth of 12.19 m, and a shoreline length of 8,420 m (Hulsey, 1956; Browne, 1967), but since that time siltation has reduced the maximum depth to 10.5 m (Jackson, 1977). Lake Wedington, located 25.8 km west of Fayetteville, Arkansas, was constructed in 1937 by the U.S. Forest Service. The lake has a surface area of 33 ha, a maximum depth of 12 m, a mean depth of 4.48 m and a shoreline length of 6,115 m (Allman, 1952; Owen, 1952).

Materials And Methods

Both lakes were censused once a week on the same day until all waterbirds were counted from the second week September to the third week of November in 1993 and 1995 using 7 X 35 binoculars and a 20X power telescope. Three vantage points were selected in which all possible shoreline and open water could be carefully scanned. Birds were counted and identified to species (Robbins et al., 1983).

Site characteristics, including lake surface area, lake shoreline length, and lake depth, were obtained from previous studies (Allman, 1952; Hulsey, 1952; Owen, 1952; Browne, 1967; Jackson, 1977). Water quality properties measured in 1995 included surface water temperature, pH, turbidity, conductivity, and dissolved oxygen. These variables were measured on a weekly basis on the day that censusing occurred. Water temperature was measured using a mercury thermometer, and pH was measured using pH indicator paper. Dissolved oxygen, conductivity, and turbidity were measured using portable water analysis instruments. Dissolved oxygen was measured using YSI Model 57 Oxygen meter. Conductivity was measured using YSI Model 33 S-C-T meter, and turbidity was measured using Model 16800 turbidimeter. Macrophyte and macroinvertebrate abundances were obtained from previous studies (Sullivan and Brown 1994; Aguila, 1993). Macrophyte abundance was measured for both lakes in the autumn of 1993, where macrophyte mean biomass was calculated in order to obtain estimates of total biomass for standing crop for each lake (Sullivan and Brown, 1994). Macroinvertebrates were sampled in autumn 1993 at three different water depths for both lakes using dredges, corers, and pond nets (Aguila, 1993). One single transect, extending from littoral zone to pelagic zone, was established in each lake which varied in length depending on the morphometric characteristics of the lake, in order to obtain the three selected depths. Three sampling stations were placed in the transect as follows: shallow (3-4 m), intermediate (6-7 m), and deep (9-10 m) in which two bottom samples were taken at each station. Human activity was monitored on a weekly basis in 1993 (Erwin, 1993) and 1995. In the autumn of 1993, Erwin obtained information on human activities, such as fishing, camping, picnicking, and hiking on both lakes. Interviews with lake managers and rangers, direct observations, and weekly records of fishing permits were evaluated twice a week. During weekly waterbird censuses in 1995, the number of boats in each lake were counted.

Data compilation consisted of species lists and relative abundance. Wilcoxon matched pairs signed rank test was used in data analysis because the data were not normally distributed.

Results

Lake Fayetteville had a consistently higher species richness and number of waterbirds than Lake Wedington over the 10 week sampling interval for both years (Table 1). Lake Fayetteville had a total of 21 species in 1993 and 26 species in 1995 compared to only 12 species observed on Lake Wedington for each of the years (Table 2). Overall observed number of birds per hectare was significantly higher ($P < 0.05$) for Lake Fayetteville than Lake Wedington for both years. The second week of September to the third week of October showed relatively low species richness and abundance (Table 1). Pied-billed Grebes, Great Blue Herons, and Belted Kingfishers were the most frequently observed species during the entire study. Increased numbers of waterbirds during the second week of September 1995 at Lake Fayetteville was due to migration of Blue-winged Teal and Wood Ducks (Table 1). Peak migration of waterbirds, especially waterfowl, occurred during the last four weeks of sampling from the last week of October through November (Table 1) during which Canada Goose, American Coot, Mallard, Northern Shoveler, and Gadwall species exhibited

Table 1. Species richness and number of waterbirds observed during the 10 week sampling period on Lake Fayetteville and Lake Wedington in 1993 and 1995.

		Lake Fayetteville				Lake Wedington			
		Number of Species		Birds/Hectare		Number of Species		Birds/Hectare	
Week	Month	1993	1995	1993	1995	1993	1995	1993	1995
1	September	6	4	0.38	0.30	4	2	0.12	0.06
2	September	5	8	0.20	1.45	0	3	0	0.24
3	September	6	4	0.38	0.42	2	1	0.18	0.06
4	October	5	4	0.33	0.36	2	1	0.09	0.15
5	October	8	8	0.45	0.45	4	1	0.24	0.09
6	October	8	9	0.55	1.32	2	1	0.09	0.24
7	October	6	17	0.19	9.73	4	8	0.42	5.18
8	November	13	16	3.67	8.95	4	3	2.09	0.24
9	November	14	10	1.19	8.34	3	4	0.30	0.27
10	November	12	9	1.64	8.22	3	2	0.39	0.27
	Average	**8.3**	**8.9**	**0.90**	**3.95**	**2.8**	**2.6**	**0.39**	**0.68**

peak numbers, especially at Lake Fayetteville (Table 2).

Species were grouped into four guilds based on foraging habits and food selection (Table 3). Guilds include surface plant feeders (Canada Goose, Mallard, Gadwall, American Widgeon, Northern Shoveler, Blue-winged Teal, Green-winged Teal, Wood Duck, and American Coot), surface fish feeders (White Pelican, Great Blue Heron, Green Heron, Little Blue Heron, Ringbilled Gull, Caspian Tern, and Belted Kingfisher), diving invertebrate feeders (Redhead, Canvasback, Ring-necked Duck, Lesser Scaup, Bufflehead, and Ruddy Duck), and diving fish feeders (Common Loon, Horned Grebe, Pied-billed Grebe, Double-crested Cormorant, Hooded Merganser, and Red-breasted Merganser). Numbers of surface feeding birds were significantly greater at Lake Fayetteville than Lake Wedington in both 1993 and 1995, whereas the number of diving feeding birds showed no difference between the two lakes in both 1993 and 1995 (Table 3).

Water temperature, pH, turbidity, and dissolved oxygen were not significantly different between the lakes, but conductivity was consistently higher ($P < 0.01$) for Lake Fayetteville (Table 4). Macrophyte abundance was consistently higher in Lake Wedington compared to Lake Fayetteville for both mean biomass (143.6 g/m^2 and 110.6 g/m^2 respectively) and estimated total biomass for standing crop (3430.9 kg and 2285.8 kg respectively). Total numbers of macroinvertebrates were similar for Lake Fayetteville and Lake Wedington (1647 and 1670 respectively). Human activity was not significantly different between the lakes in either 1993 or 1995 (Table 4) and dropped rapidly as the weather cooled. Over the course of the study, in 1993, Lake Fayetteville had a 94% decreased in overall human activity (fishing, camping, picnicking, and hiking) compared to 92% on Lake Wedington. However, considering only fishing activity a 90% decreased occurred on both lakes. In 1995, both Lake Fayetteville and Lake Wedington exhibited a 100% decrease in boat use over the censusing period in which the last three weeks no activity was reported on the lakes.

Discussion

Species richness and number of waterbirds per hectare were significantly higher for Lake Fayetteville than Lake Wedington over the 10 week sampling interval in 1993 and in 1995 (Table 1). Connor and McCoy (1979) and Suter (1994) reported that larger lake surface areas attract more

Table 2. Number of weeks each species was observed in a 10 week period from September to November, the high count, and high count date of waterbirds observed at Lake Fayetteville and Lake Wedington in 1993 and 1995.

Species	Lake Fayetteville				Lake Wedington			
	Weeks Seen		High Count (Date)		Weeks Seen		High Count (Date)	
	1993	1995	1993	1995	1993	1995	1993	1995
Common Loon	0	1	0	1 (08 Nov)	1	0	1 (12 Sept)	0
Horned Grebe	4	1	6 (11 Nov)	3 (08 Nov)				
Pied-billed Grebe	8	9	16 (10 Oct)	25 (02 Nov)	7	9	10 (31 0ct)	20 (02 Nov)
American White Pelican	0	1	0	1 (18 Oct)				
Double-crested Cormorant	4	4	1 (12 Oct)	3 (25 Oct)	1	1	1 (03 Nov)	1 (02 Nov)
Canada Goose	0	6	0	154 (21 Nov)				
Mallard	6	7	19 (31 Oct)	95 (21 Nov)	0	1	0	3 (02 Nov)
Gadwall	4	5	100 (31 Oct)	193 (08 Nov)	1	1	58 (27 Oct)	50 (02 Nov)
AmericanWidgeon	1	1	2 (31 Oct)	2 (08 Nov)				
Northern Shoveler	3	4	17 (31 Oct)	80 (02 Nov)	0	1	0	11 (02 Nov)
Blue-winged Teal	1	2	14 (14 Sept)	15 (26 Sept)				
Green-winged Teal	2	1	3 (03 Nov)	10 (02 Nov)	0	1	0	46 (02 Nov)
Wood Duck	6	7	20 (22 Oct)	17 (25 Oct)				
Redhead	0	1	0	16 (02 Nov)				
Canvasback	0	1	0	1 (08 Nov)				
Ring-necked Duck	0	1	0	45 (02 Nov)	1	1	6 (27 Oct)	33 (02 Nov)
Lesser Scaup	2	2	60 (31 Oct)	8 (08 Nov)	1	0	3 (27 Oct)	0
Bufflehead	4	4	16 (11 Nov)	27 (21 Nov)				
Hooded Merganser	1	1	3 (31 Nov)	10 (02 Nov)	0	1	0	7 (02 Nov)
Red-breasted Merganser	2	1	1 (07 Nov)	2 (25 Oct)				
Ruddy Duck	3	4	29 (14 Nov)	31 (02 Nov)	2	1	5 (17 Nov)	4 (08 Nov)
Great Blue Heron	lO	10	3 (31 Oct)	3 (17 Sept)	2	2	2 (31 Oct)	1 (26 Sept)
Green Heron	2	1	2 (12 Sept)	1 (26 Sept)	1	1	1 (14 Sept)	1 (17 Sept)
Little Blue Heron	2	0	2 (28 Sept)	0				
American Coot	6	5	12 (31 Oct)	351 (15 Nov)	2	0	3 (10 Oct)	0
Ring-billedGull	3	0	2 (03 Nov)	0				
Caspian Tern	0	1	0	2 (17 Sept)				
Belted Kingfisher	10	8	3 (19 Sept)	3 (18 Oct)	8	5	3 (11 Nov)	1 (08 Nov)
Spotted Sandpiper					1	0	1 (14 Sept)	0

Table 3. Mean number of waterbirds per hectare observed in the four guilds during the 10 week sampling period in 1993 and 1995.

	1993		1995	
Guild[a]	Lk. Fayetteville	Lk. Wedington	Lk. Fayetteville	Lk. Wedington
Surface Plant Feeders	0.451**	0.191	3.340**	0.333
Surface Fish Feeders	0.072*	0.045	0.072*	0.024
Diving Invertebrate Feeders	0.265	0.048	0.317	0.112
Diving Fish Feeders	0.110	0.109	0.220	0.203

[a] See text for species included in each guild.
* Indicates a significant difference between reservoirs, $P < 0.05$.
** Indicates a significant difference between reservoirs, $P < 0.01$.

Table 4. Mean values for water chemistry parameters and index of human activity for Lake Fayetteville and Lake Wedington.

	Lake Fayetteville	Lake Wedington
Water Chemistry		
Turbidity (NTU)	15.5	10.0
Dissolved Oxygen (p.p.m.)	11.1	10.4
Conductivity (µmhos/cm)	148.0**	102.0
pH	6.6	6.6
Temperature (°C)	12.4	12.8
Human Activity		
1993 (persons/day)		
Overall[a]	33.6	34.7
Fishing	14.9	12.9
1995 (boats/day)	2.0	1.2

[a] Includes fishing, camping, picnicking, and hiking.
** Indicates a significant difference between reservoirs, $P < 0.01$.

birds. Therefore, surface area of the two lakes was used to standardize the number of birds per hectare since Lake Fayetteville has twice the surface area as Lake Wedington. Nevertheless Lake Fayetteville had significantly more waterbirds per hectare, specifically surface plant and surface fish feeders, than Lake Wedington (Table 3). Number of diving invertebrate and diving fish feeders were not significantly different between the two lakes.

Lake surface area probably accounts for much of the difference in waterbird numbers between the lakes, but why is Lake Fayetteville dominated by surface feeders? Siltation of Lake Fayetteville has resulted in extensive shallow areas, which probably makes food readily available for surface feeding birds. Water quality measurements between the lakes were similar, only conductivity was significantly different (Table 4). This difference in conductivity is only slight and probably does not directly affect bird utilization, however, it indicates higher siltation rates for Lake Fayetteville. Food availability appears to be similar between the two lakes, especially macroinvertebrates (Aguila, 1993). *Chaoborus* and the family Tubificidae dominated the total taxa of Lake Fayetteville and Lake Wedington (89% and 82% respectively). Comparable macroinvertebrate numbers may explain why both lakes had similar numbers of diving foraging birds. Macrophyte biomass was higher for Lake Wedington than Lake Fayetteville in the autumn of 1993 (Sullivan and Brown, 1994). In 1992, however, most of the macrophytes were eliminated by herbicides in Lake Fayetteville (Sullivan and Brown, 1994). Based on casual observation, we suspect in 1995 that macrophytes may be just as or even more abundant in Lake Fayetteville than Lake Wedington. The mean number of surface plant feeders increased approximately eight fold from 0.451 birds per hectare in 1993 to 3.340 birds per hectare in 1995 for Lake Fayetteville (Table 3). This increase was probably due to regrowth of aquatic macrophytes. *Potamogeton* (pondweed), *Zannichellia* (horned pondweed), Polygonum (smartweed), *Ceratophyllum* (coontail), and *Lemna* (duckweed) are excellent food sources for waterfowl (Darling and Cottam, 1936). Estimates of total biomass of these preferred food sources was similar between the two lakes (Sullivan and Brown, 1994). However, duckweed was more abundant in Lake

Fayetteville for both 1993 and 1995, which could influence the number of surface foragers on Lake Fayetteville. Although Lake Fayetteville was twice the size as Lake Wedington, human activity did not appear to affect abundance of waterbird assemblages. When peak waterbird migration occurred, most human activity ceased.

Conclusions

Several characteristics were evaluated in order to explain relative abundance of waterbirds between the two lakes. Water quality, number of macroinvertebrates, and human activity monitored on and around the two lakes had the least influence on explaining the difference in waterbird abundance between the lakes. Lake surface and water depth seem to be major factors affecting waterbird utilization. Lake surface area probably explains some of the variation between the two lakes. In addition, eutrophication of Lake Fayetteville has resulted in extensive shallow areas which enhances food accessability for surface feeders. Increase of shallow water and the probable regrowth of macrophytes since herbicide use in 1992 on Lake Fayetteville may help explain why surface feeders are becoming more abundant on Lake Fayetteville.

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The Fish Community of Indian Bayou, A Coastal Plain Stream of Remarkable Species Richness in the Lower White River Drainage of Arkansas

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Abstract

It is increasingly important to identify unique aquatic ecosystems in the coastal plain lowlands of Arkansas, because of the extensive human-induced alteration of aquatic habitats and loss of fish diversity in that region. Indian Bayou, part of a small (103 km^2), chute-fed drainage system off the lower White River in Monroe County, Arkansas, has a fish community that is unique among Delta streams in darter (Percidae) species richness. Twenty-five fish samples collected by seine and rotenone from the Indian Bayou drainage system over an 18-year period produced 62 fish species, including 13 darter species. The fish community at one collecting site on the Indian Bayou mainstream remained remarkably stable during the study, and 12 of the darter species were found there between 1971 and 1989. The continued existence of this unique fish assemblage is now threatened by proposals to divert large amounts of water from the White River for agricultural purposes, dredge a wider and deeper navigation channel in the White River, and construct a new interstate highway.

Introduction

The increasing demands of an expanding human population on aquatic resources have caused extensive degradation of aquatic habitats throughout Arkansas (Robison and Buchanan, 1988). Nowhere is this degradation more apparent than in the Mississippi Delta. In the mid 1800s, approximately one-half of the Delta consisted of forested wetlands; today only about ten percent of those wetlands remain (Mallory, 1994). Agricultural activities have caused most of the habitat alteration in the lowlands of Arkansas, and the conversion of forested wetlands to cropland has greatly reduced the species diversity in fish faunal assemblages. It is, therefore, increasingly important to identify and protect remnant fish communities that are more representative of the historically high diversity in the Delta.

Aquatic environments associated with the lower White River in the Delta are now of special concern because of increasing demands to divert large amounts of water from that river, primarily for agricultural purposes. These demands for surface water withdrawal are due to groundwater level declines that have occurred in the alluvial aquifer in most of eastern Arkansas (Louthian, 1995). The recently proposed Grand Prairie Irrigation Project seeks to withdraw approximately 46 m^3 of water per second from the White River at DeVall's Bluff (S. Filipek, Arkansas Game & Fish Commission [AGFC], pers. comm.). Extensive water diversion during summer low-flow periods would decrease water levels in chutes, bayous, natural lakes, and other associated wetlands. Dewatering of these environments would cause extirpation of fish communities and other aquatic organisms. Filipek et al. (1987) discussed the biological implications of the alteration of stream flow and the need to maintain adequate flow in Arkansas streams.

The AGFC and Arkansas Department of Pollution Control and Ecology (ADPCE) are presently compiling information to determine proper allocation flow levels for the White River. However, a single state agency, the Arkansas Soil and Water Conservation Commission, whose nine members are appointed by the governor, has sole authority to set the minimum flow level for all instream uses. Arkansas is one of the few states where the legislature has given this jurisdiction to only one agency.

Another potential threat to aquatic environments along the lower White River is a plan proposed by the U.S. Army Corps of Engineers to dredge a deeper, wider navigation channel in the White River. This project, which has been periodically promoted during the past two decades, would double the width of the present navigation channel and increase its depth by 50 percent. Dredging the lower White River could cause the dewatering of associated wetlands and result in substantial loss of fish and wildlife habitat.

Indian Bayou is a stream, approximately 19.3 km long, on the northern edge of the White River National Wildlife Refuge. Even though the United States Geological Survey (USGS) classifies it as a distinct drainage system with a drainage area of 103 km^2, including Indian Bay (Sullavan, 1974), water from the White River frequently flows through

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Indian Bayou as part of a chute-fed system. During periods of high flow, current from White River enters Cut-Bluff Slough at navigation mile 80, flows into Maddox Bay, then into Indian Bayou before reentering the White River (Fig. 1), a total distance of approximately 47 km. At least two other sloughs provide access points for water to enter Indian Bayou from the White River during high flows, and it often receives water from the larger Green River-Mill Bayou system to the north in Monroe County. Therefore, Indian Bayou is part of a network of wetland drainages of the White River floodplain. In years of normal or high rainfall, current from the White River flows through this system year-round. There are no data available on how much of the annual stream flow of Indian Bayou comes from the White River and how much is due to runoff and groundwater discharge. Even though its watershed is small and lies entirely within Monroe County, Indian Bayou has an assemblage of fishes that is unique among Delta drainages of the state and is remarkable in comparison to all other areas of Arkansas. I herein report on fish samples taken from Indian Bayou over an 18-year period (1971-1989) to document its remarkable species richness and stability, especially among the percids.

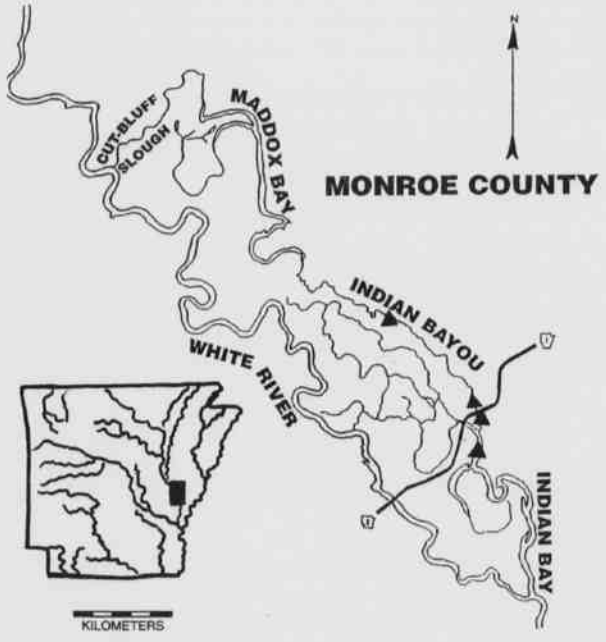

Fig. 1. Indian Bayou illustrating the mainstream drainage sequence. Triangles indicate mainstream sampling sites.

Materials and Methods

Eleven fish samples were made from four localities on the Indian Bayou mainstream between April 1971 and November 1989. Eight samples came from Indian Bayou at State Highway 1, approximately 13 km above its confluence with the White River. At that site, a 100 m section of the stream was sampled; seven of the samples were taken with a 3 x 1.2 m nylon seine of 3.2 mm mesh, and the eighth sample was made with an ichthyocide (rotenone) in a backwater area. The State Highway 1 locality was sampled twice in 1971, and once each in 1972, 1974, 1976, 1977, 1988, and 1989. The lack of roads and general inaccessibility throughout most of the Indian Bayou watershed caused much of the sampling to be focused at the State Highway 1 site. The other three Indian Bayou localities were sampled by seine in 1971 and 1972. Fourteen other sites in the Indian Bayou drainage system were sampled once each between 1973 and 1989 (seven with seines and seven with rotenone). Habitat features recorded during each sampling event were substrate composition and distribution, current (estimated as none, slow, moderate, or swift), water temperature, maximum depth, depth of capture, and turbidity.

At each collecting site, all available habitats were sampled as completely as possible to obtain a sample of fishes representative of the natural abundance of all species at the site. Specimens were preserved in 10% formalin and later transferred to 45% isopropanol. All fish species present at each site were identified in the laboratory from preserved samples, and most of the specimens were deposited in the Westark Community College Zoology Collection. A few specimens were deposited in the Texas Natural History Collection of the University of Texas and in the Tulane University Museum of Natural History.

Results and Discussion

Sixty-two fish species were collected from the Indian Bayou drainage system with 48 found in the Indian Bayou mainstream (Table 1). This species richness is remarkable because of the drainage area size, the types and amount of collecting effort, and the number of darter species present. A comparison with other drainages throughout the Mississippi Delta of eastern Arkansas (and other regions of the state) also shows the unusual richness of the Indian Bayou fish community. Data for these comparisons were from fish samples collected by the ADPCE, the published reports of stream surveys by other researchers, and from my own unpublished results of fish collections taken during the past two and a half decades.

In the mid 1980s, the ADPCE subdivided Arkansas into six ecoregions based on the homogeneity of land surface

Table 1. Fish species collected from Indian Bayou and associated waters (tributary streams, natural lakes and swamps), April 1971-November 1989.

Species	Indian Bayou at St. Hwy 1	Other Indian Bayou sites	Associated waters
Lepisosteus oculatus	X		X
Lepisosteus osseus	X		X
Lepisosteus platostomus			X
Amia calva			X
Dorosoma cepedianum			X
Dorosoma petenense	X		X
Esox americanus	X	X	X
Esox niger	X		X
Cyprinella venusta	X	X	X
Cyprinus carpio	X		
Hybognathus hayi	X	X	X
Hybognathus nuchalis	X	X	X
Lythrurus fumeus	X	X	X
Macrhybopsis storeriana	X	X	
Notemigonus crysoleucas	X		X
Notropis amnis			X
Notropis atherinoides	X	X	X
Notropis buchanani	X	X	
Notropis maculatus			X
Notropis texanus	X	X	X
Notropis volucellus	X	X	X
Opsopoeodus emiliae	X	X	X
Pimephales notatus	X		
Pimephales vigilax	X	X	
Ictiobus bubalus			X
Ictiobus cyprinellus			X
Minytrema melanops	X	X	X
Ameiurus natalis	X		X
Noturus gyrinus	X	X	X
Noturus nocturnus	X		
Pylodictis olivaris			X
Aphredoderus sayanus	X	X	X
Fundulus notatus		X	X
Fundulus olivaceus	X	X	X
Gambusia affinis	X	X	X
Labidesthes sicculus	X	X	X
Morone chrysops			X
Lepomis cyanellus			X
Lepomis gulosus	X	X	X
Lepomis humilis		X	X
Lepomis macrochirus	X	X	X
Lepomis megalotis	X	X	X
Lepomis miniatus			X
Micropterus punctulatus	X	X	X
Micropterus salmoides	X		X
Pomoxis annularis			X
Pomoxis nigromaculatus	X		X
Elassoma zonatum	X		
Crystallaria asprella	X		
Etheostoma asprigene	X	X	X
Etheostoma chlorosomum	X	X	X
Etheostoma fusiforme			X
Etheostoma gracile	X		X
Etheostoma histrio	X	X	
Etheostoma proeliare	X	X	X
Etheostoma stigmaeum	X		X
Percina caprodes	X	X	X
Percina maculata	X	X	
Percina sciera	X		
Percina shumardi	X		
Percina vigil	X		
Aplodinotus grunniens			X

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forms, natural vegetation, soil types and land uses (Fig. 2). Fishes were sampled from reference streams having the least amount of point source and non-point source disturbances in each ecoregion (Giese et al., 1987; Keith, 1987; Rohm et al., 1987). One locality was sampled in each stream during the spring high-flow period with trammel nets and during the summer low-flow period with rotenone and an electroshocker. Fish communities of the reference streams were distinctively different among the ecoregions with the Delta Ecoregion streams having the lowest species richness; the dominant fish families (percent of all species) in Delta Ecoregion streams were as follows: Centrarchidae (24%), Cyprinidae (20%), Catostomidae (10%), Ictaluridae (10%), and Percidae (10%). The Indian Bayou mainstream fish community differed substantially from other Delta streams in family dominance with the same five families comprising the following percentages of the fish species present: Cyprinidae (27%), Percidae (25%), Centrarchidae (20%), Catostomidae (6%), and Ictaluridae (6%). Matthews et al. (1992) also found that the Delta Ecoregion of Arkansas had a distinctive fish assemblage correlated with generally low water quality, and they demonstrated a relationship between fish distribution and a set of 14 water quality variables.

Table 2 shows the high diversity of the Indian Bayou fish community compared to seven other Delta Ecoregion

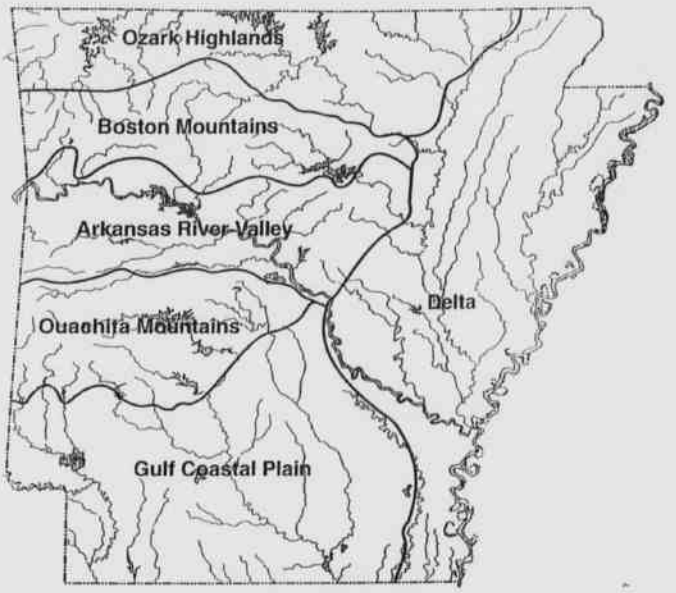

Fig. 2. Ecoregions of Arkansas.

Table 2. Comparison of the fish communities and other attributes of Indian Bayou and seven other streams in the Delta Ecoregion of Arkansas.

Stream	Drainage area (km^2)	Sampling methods***	Total fish species	Total darter species	Greatest no. darter species at one site	Darter community SI****	Native cyprinid species
Indian Bayou drainage system*	103 (54)	S,R	62 (48)	13 (12)	12	—	15 (13)
Boat Gunwale Slash	92	R,T	40	3	3	0.40	2
Second Creek	155	R,T	36	4	4	0.50	6
Wattensaw Bayou	614	S,E,H,T,M	48	3	3	0.40	13
Village Creek	503	S,R,T,D, G,HL	42	2	2	0.29	8
Bayou DeView	1816	S,R,T,D	52	6	6	0.76	7
Bayou Meto	1606	S,E,H,T,M,	64	10	6	0.64	12
Bayou Bartholomew**	5799 [3074]	S	86(79) [62]	17(16) [8]	(15) [5]	0.83 [0.60]	20 [19]

* Numbers in parentheses are for the Indian Bayou mainstream.
** Numbers in brackets are for the Arkansas portion of Bayou Bartholomew, numbers in parentheses are for the Louisiana portion.
*** D(dipnet), E(electroshocker), G(gill net), H(hoop net), HL(hook and line), M(minnow trap), R(rotenone), S(seine), T(trotline).
**** Similarity with Indian Bayou based on the similarity index (SI) of Odum(1971).

streams in eastern Arkansas. Four of the streams, Boat Gunwale Slash (Monroe Co.), Second Creek (Woodruff, Cross, and St. Francis cos.), Village Creek (Randolph, Lawrence, and Jackson cos.), and Bayou DeView (Craighead, Poinsett, Cross, Jackson, Woodruff, and Monroe cos.), were sampled by the ADPC&E as least disturbed reference streams of that ecoregion. Two streams, Bayou Meto (Pulaski, Lonoke, and Arkansas cos.) and Wattensaw Bayou (Lonoke and Prairie cos.), were intensively sampled by Heckathorn (1993a), and Bayou Bartholomew in southeastern Arkansas (Jefferson, Lincoln, Desha, Drew, Chicot, and Ashley cos.) and northeastern Louisiana (Moorehouse Par.) was surveyed by Thomas (1976). Village Creek and Bayou DeView, two of the streams studied by the ADPC&E, were also surveyed by Holt and Harp (1993) and Mauney and Harp (1979), respectively. Table 2 combines data from these stream surveys, as well as from three of my samples from Bayou DeView and two from Boat Gunwale Slash.

Considerable information exists for North American streams showing that the number of fish species occurring in a drainage increases with increased drainage size (Horwitz, 1978; Jenkins and Burkhead, 1993; Sheldon, 1988). The data in Tables 2 and 3 generally support this trend for Arkansas streams, but Indian Bayou stands out as an obvious exception. The Indian Bayou drainage is far smaller than the drainages of five of the seven Delta Ecoregion streams compared, but its overall species richness (62 species) exceeded that of all Delta streams except Bayou Meto and Bayou Bartholomew. The Bayou Meto watershed is over 15 times larger than that of Indian Bayou and drains a small portion of the foothills of the Interior Highlands of central Arkansas as well as the Delta. Bayou Meto was subjected to a well-documented point source contamination by dioxin in the 1970's (Heckathorn, 1993b), and Heckathorn (1993a) found that its fish community differed from that of an undisturbed reference stream, Wattensaw Bayou, primarily by the absence of rare species (presumably those that are more sensitive to disturbance) in the former. Indian Bayou had the same number of fish species as the Arkansas portion of Bayou Bartholomew, which has a drainage area 30 times larger.

The fish species richness of Indian Bayou is almost certainly related to its proximity to the White River main channel. Gorman (1986) was one of the first researchers to consider the influence of downstream conditions on upstream fish communities. Osborne and Wiley (1992), in a study of the warmwater fish communities of three Illinois drainage basins, found that fish species richness in a given stream segment was more closely related to the downstream link (stream size at the next downstream confluence) than to any other measure of stream size including drainage area and stream order. They reported significantly higher numbers of fish species were collected from tributary streams located lower in a drainage network and connected to a main channel system than from similarly sized streams located in the headwaters. The influence of the White River main channel on the fish community of the Indian Bayou mainstream (a second order segment) was substantiated by the frequent collection of large numbers of the riverine species, *Macrhybopsis storeriana*, *Notropis atherinoides*, *Pimephales vigilax*, and *Percina shumardi* in Indian Bayou. Several other species normally associated with larger order streams were also found there (Table 1).

The uniqueness of the Indian Bayou fish community is primarily found in its rich assemblage of darters (family: Percidae, tribe: Etheostomatini). No other Delta Ecoregion stream in Arkansas, regardless of watershed size, is known to have as many darter species, although the Louisiana portion of Bayou Bartholomew has more. Even the lower White River mainstream has only 11 reported darter species (Robison and Buchanan, 1988). It is not appropriate to compare the darter diversities of Indian Bayou and the other Delta Ecoregion streams by any of the commonly used diversity indices because of differences in sample size, number, and sampling techniques used by various researchers. However, it is possible to quantify the similarities of Delta streams with Indian Bayou with respect to presence-absence of darter species by using the index of similarity of Odum (1971), S=2C/A+B, where C is the number of darter species common to both streams, A is the total number of darter species in Indian Bayou, and B is the total number of darter species in the other stream being compared (Table 2). The darter community of Indian Bayou was similar to that of Bayou DeView, a Delta Ecoregion stream with a much larger drainage area. However, the greatest similarity was with the entire Bayou Bartholomew drainage. All other Delta streams compared had low similarity indices.

Darters form a functional type or guild (Huston, 1994) within aquatic ecosystems due to their trophic level similarities and other similar niche utilization patterns. Most darters are small, first- and second-level carnivores that feed mainly on microcrustaceans as juveniles and on immature aquatic insects as adults (Page, 1983). More importantly, darters as a group are very sensitive to environmental disturbance, and various authors have cited their value as indicators of good water quality and overall aquatic health (Burr and Warren, 1986; Jenkins and Burkhead, 1993; Kuehne and Barbour, 1983; Page, 1983). Even though individual species vary in their sensitivity to habitat disturbance (e.g., *Percina caprodes* tolerates a wider range of habitat and water quality parameters than most darters), darters are probably better indicators of environmental disturbance than any other taxon of native fishes.

Twelve of the thirteen species of darters found in the Indian Bayou watershed occurred in the Indian Bayou mainstream. Three of the four currently recognized darter genera were represented, and over 30% of all darter species known to occur in Arkansas were found there. Indian Bayou

Table 3. Fish community and other characteristics of streams of various drainage areas in the five ecoregions outside the Delta of Arkansas.

Stream	Ecoregion*	Data source	Drainage area (km^2)	Years sampled	Number of samples	Total fish species	Darter species	Native cyprinid species
Moro Creek	G	Robison and Winters (1978), Keith (1987)	1173	1972-77, 1985-86	34	63	14	16
Ten Mile Creek	G	Jeffers and Bacon (1979)	155	1976-79	28	53	9	10
Caddo River	Ou	Fruge (1971), Dewey and Moen (1978)	757	1970-71, 1974-75	119	89	21	19
Cossatot River	Ou, G	Cloutman and Olmsted(1974), Keith (1987)	312	1972, 1984-85	21	53	9	15
Gulpha Creek	Ou	Buchanan et al. (1978)	124	1978	32	27	2	7
Big Creek	Oz	Jackson and Harp (1973)	174	1970-71	39	30	4	10
Buffalo River	B, Oz	Cashner and Brown (1977)	3582	1965-66	30	48	9	15
Saline River	Ou, G	Reynolds (1971)	8241	1969-71	62	85	21	23
Jane's Creek	Oz	Fowler and Harp (1974)	203	1971-72	40	52	10	17
Piney Creek	Oz	Matthews and Harp (1974), Matthews(1978)	460	1972-73	>18	47	4	17
Strawberry River	Oz	Robison and Beadles (1974), Robison (1979)	2100	1967-78	37	107	23	30
Clear Creek	B	Buchanan's collections	668	1971-1989	31	40	10	13
Lee Creek	B	Buchanan's collections	1291	1971-1993	29	52	13	12
Mulberry River	B	Olmsted et al. (1972)	970	1972	19	57	11	13
Poteau River**	A	Cross and Moore (1952), Buchanan's collections	4908 [1572]	1947, 1973-1993	>60 [23]	93 [51]	16 [9]	21 [12]
Vache Grasse Creek	A	Buchanan's collections	326	1972-1996	37	55	10	15

* Letters represent the following ecoregions: A (Arkansas River Valley), B (Boston Mountains), G (Gulf Coastal Plain), OU (Ouachita Mountains), Oz (Ozark Highlands).

** Numbers in brackets are for the Arkansas portion of the Poteau River drainage.

is also noteworthy for its diversity of native cyprinids, with 13 species of minnows. The species richness of minnows in Indian Bayou is greater than that of most other Delta Ecoregion streams; however, minnows do not form a natural functional type like the darters. Cyprinids exhibit a wide range of tolerance to environmental disturbances, and while some species are environmentally sensitive, minnows as a group are not necessarily reliable indicators of water quality. However, a high cyprinid species richness probably indicates good water quality.

The darter species richness of Indian Bayou is not only unique to the Delta Ecoregion of Arkansas, but is apparently unmatched by streams similar in watershed size in all other ecoregions of the state. In the reference stream fish surveys of Keith (1987), the only other Arkansas stream that had darter diversity exceeding that of Indian Bayou was Moro Creek (also surveyed by Robison and Winters, 1978) in the Gulf Coastal Plain Ecoregion. Fourteen darter species were reported from Moro Creek, a stream with a drainage area eleven times that of Indian Bayou. Table 3 provides a comparison of Indian Bayou with streams of different drainage areas in the five ecoregions of Arkansas outside the Delta. All stream data reported in Table 3 are based on more fish samples than I obtained from Indian Bayou. Some streams with large drainage areas in other ecoregions have more darter species than Indian Bayou. The extensively sampled Caddo, Poteau, Saline, and Strawberry rivers (all with drainage areas >750 km^2) have the most darter (and total fish) species and are among the most species-rich streams in North America. Matthews and Robison (1988) concluded that the high species richness of the large stream drainages in Arkansas (eastern-draining or southern slope streams in the eastern Ozark uplift, and in the Ouachita River and Saline River) is related to their position as ecotones, with those streams including both upland and lowland fish species. Streams listed in Table 3 that have drainage areas similar in size to Indian Bayou (Big, Jane's, Gulpha, and Ten Mile creeks) have fewer darter species and total fish species.

Indian Bayou is also noteworthy for its darter species richness at a single collecting locality (State Highway 1) and for the temporal stability of that richness. The first fish sample taken from that site (18 April 1971) yielded nine species of darters, as did the last sample collected (10 November 1989). All 12 darter species found at that locality were collected by the fourth sample (12 August 1974). The number of individuals collected and the number of darter species taken during summer low-flow sampling at State Highway 1 remained relatively constant over the 18-year sampling period. Table 4 lists the darter species collected from all Indian Bayou samples combined in decreasing order of abundance; general habitat preferences for each species are also presented (taken largely from Page, 1983). No other collecting locality in the Delta Ecoregion of Arkansas has produced 12 darter species; however, 15 species of darters were reported from one locality on Bayou Bartholomew near Bastrop, Louisiana (Thomas, 1976). The total number of fish species (46) collected at State Highway 1 on Indian Bayou is also remarkable.

Few individual localities in other ecoregions of Arkansas equal the State Highway 1 site in species richness of darters or total fish species, and few authors have commented on the number of fish species occupying a stream site. Keith (1987) found that the average number of fish species collected per site in reference streams in all Arkansas ecoregions was similar (28.8-36.6 species per site), even though the total number and composition of species differed for each ecoregion. Robison (1979) reported a locality of unusual species richness on the Strawberry River (Ozark Ecoregion), where six fish samples over an eleven-year period yielded 51 species, including 17 species of darters. Jenkins and Burkhead (1993) studied Virginia streams and found that small creeks typically had 2-20 species per site, medium-sized streams 15-30, and rivers 20-40, based largely on samples along a 300 - 600 m stream section per site under normal or low water levels. Localities in the Clinch River drainage, Virginia, yielded the largest numbers of species per site (three sites with 51, 46, and 52 species), and Jenkins and Burkhead considered these numbers to be quite high for North American fresh waters. The richest sites reported are from the Duck River, Tennessee (Etnier and Jenkins, 1980), where several collections yielded more than 90 species at one site, and from the Tombigbee River, Mississippi (Boschung, 1989), where a station sampled between 1963-1980 produced 92 species.

Even though darters represent a general functional type within aquatic ecosystems, most darter species have strict habitat requirements. Therefore, it is unusual to find many species of percids at one site, even when a large segment of the stream is sampled. The small segment (100 m) of Indian Bayou sampled at State Highway 1 yielded darter species that prefer a variety of habitat combinations (Table 4). The habitat variety in Indian Bayou was most obvious during summer low-flow periods, with different areas having slow to swift current and substrates predominantly of silt and clay but also with some sand and gravel. The substrate in one 10-m riffle was composed largely of shells and shell fragments from the introduced Asiatic clam, *Corbicula*. This riffle was highly favored by *Etheostoma histrio* and *Percina shumardi*, two of the most frequently collected darters. During every sampling event, the mainstream of Indian Bayou had a moderate to swift current. Backwater areas were present during low-flow periods. The most abundant darter was the riverine form, *P. shumardi*, followed by the predominantly quietwater form, *E. proeliare*. Two other riffle-dwelling species, *E. asprigene* and *E. histrio*, and one other quietwater form, *E. chlorosomum*, were also numerous. The darter least specialized in habitat requirements, *P. caprodes*, was fre-

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quently collected, but not in large numbers.

Three species collected from Indian Bayou represent noteworthy disjunct populations. My collections represent the only recent records for the crystal darter, *Crystallaria asprella*, from the Delta Ecoregion portion of the lower White River drainage. The range of *C. asprella* outside Arkansas has declined drastically, and it is considered extirpated in Kentucky (Burr and Warren, 1986) and Tennessee (Etnier and Starnes, 1993). Indian Bayou has one of the few reported Delta Ecoregion populations of the speckled darter, *E. stigmaeum*. Populations of *E. stigmaeum* formerly known in the St. Francis River drainage of the Delta Ecoregion are believed to be extirpated. The taxonomy of *E. stigmaeum* is currently unsettled, and the Indian Bayou population may represent an undescribed species (Simon, 1997). *Percina vigil* (formerly *P. ouachitae*) is primarily an inhabitant of low-gradient streams below the Fall Line in Gulf Coastal drainages throughout its range. The disjunct Indian Bayou population is the only known recent record for this species from the Delta Ecoregion of Arkansas.

There are few long-term data bases documenting population trends in stream fish assemblages. Matthews (1986, 1990) and Matthews et al. (1988) provided valuable information on temporal variation and stability of some North American fish faunas. In three of the streams studied (Piney Creek, Arkansas, and Brier Creek and the Kiamichi River, Oklahoma) the fish faunas were persistent regarding presence-absence of species, and the overall faunal structure was stable over 5- to 17-year survey periods. The darter fauna of Indian Bayou remained relatively stable and persistent over an 18-year period based on abundance and presence-absence of species. No species were lost from the State Highway 1 site, and no rare species became common.

Fletcher and Burr (1992) noted that historically there has been little interest in the protection of fish species occupying lowland habitats. There are now so few streams having diverse and unusual fish communities in the Delta Ecoregion of Arkansas, that the identification of a unique ecosystem should stimulate preservation efforts. There is no evidence that other streams similar in darter species richness to Indian Bayou exist on the large (51,802 ha.) White River National Wildlife Refuge. Between 1970-81, I made 42 samples by seine, rotenone, and electroshocker in all major drainages of that refuge without finding a stream as remarkable in fish species richness as Indian Bayou. Even though the Indian Bayou mainstream lies entirely within the White River National Wildlife Refuge, that does not ensure its protection from human environmental assaults. Its fish community withstood the construction of a new and larger bridge at State Highway 1 in 1980-81 with no long-term effects on darter species richness or abundance at that site. The 1988 and 1989 samples, made several years after the bridge was completed, yielded seven and nine darter species, respectively. The relatively rapid reestablishment of the rich darter community at this site was probably related to the chute-fed flow regime from the White River, which served as a source of fishes for repopulation. Osborne and Wiley (1992) summarized evidence that large streams often provide a pool of immigrants for subsequent recolonization of their tributaries following disturbances.

Also during the 1980s, the U.S. Fish and Wildlife Service considered a proposal to build a dam (which has not been built) on Indian Bayou to create a greentree reservoir for fall and winter waterfowl habitat. The most immediate threats to the continued existence of the unique fish assemblage of Indian Bayou are the proposed plans to withdraw irrigation water from the White River just upstream from the chute feeding water into the Indian Bayou drainage system and the proposed project to dredge a wider, deeper navigation channel in the White River. Another potential environmental threat looms on the horizon: Indian Bayou lies in the middle of a proposed corridor for a new interstate highway (I-69) through Arkansas.

Even though Indian Bayou contains no federally designated endangered or threatened species, it is unique among Arkansas Delta Ecoregion streams in the diversity of its percid community and in its overall fish species richness. The stream drainages of other ecoregions that exceed Indian Bayou in darter species richness rarely have individual sampling sites that equal the richness of the State Highway I locality. Because of the extensive loss of aquatic habitats in the Delta Ecoregion, it has become increasingly important to protect not only the habitats of rare and endangered species, but also those habitats of unusual biodiversity. Lydeard and Mayden (1995) provided examples of species interactions in aquatic ecosystems that support the need to shift emphasis toward protecting communities and ecosystems rather than just particular species. My largely descriptive study of the unusual darter species richness of Indian Bayou supports the importance of future studies to test hypotheses regarding lowland fish assemblages in general and the role of darters as indicators of aquatic ecosystem stability and functioning in particular.

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Table 4. Darters of Indian Bayou mainstream listed in decreasing order of abundance for all collections (1971-89) combined, with general preferences for habitat and position in water column.

Species	% of all darter specimens collected	Preferred habitat	Stratum occupied
Percina shumardi	32.9	riffle	benthic
Etheostoma proeliare	15.9	quiet pool	benthic
Etheostoma asprigene	14.8	riffle	benthic
Etheostoma histrio	12.3	riffle	benthic
Etheostoma chlorosomum	9.9	quiet pool	benthic
Etheostoma stigmaeum	6.3	pool with current	benthic
Percina caprodes	2.7	generalist, but prefers gravel riffle or raceway	benthic
Percina sciera	2.5	gravel raceway	midwater
Crystallaria asprella	1.4	sand raceway	benthic
Etheostoma gracile	0.5	quiet pool	benthic
Percina maculata	0.5	gravel raceway	midwater
Percina vigil	0.3	sand raceway	benthic

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Revised Status of Rare and Endangered Unionacea (Mollusca: Margaritiferidae, Unionidae) in Arkansas

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Abstract

Harris and Gordon (1987) reviewed the distribution and status of 18 rare and /or endangered unionacean bivalve species (commonly referred to as clams, mussels, freshwater mussels, naiads) that occur or have occurred in Arkansas. They discussed four species that were federally listed as endangered, four species that were considered endangered or extirpated within Arkansas, four species considered threatened within Arkansas, four species of special concern within Arkansas, and two species for which the conservation status was considered uncertain due to questions regarding taxonomic validity. Numerous unionacean field surveys have been performed during 1986 1996, and a substantial database of new distributional and relative abundance information has been accumulated. Two additional unionacean species have been listed as federally endangered, one additional species has been listed as federally threatened, and one endangered species has been newly discovered within Arkansas bringing the total number of federally protected unionacean species occurring within Arkansas to eight. The conservation status of 16 additional unionacean species occurring in Arkansas is discussed also.

Introduction

During the past 35 years, abundance and species diversity of native unionacean bivalves have declined throughout the United States and Canada (Williams et al. 1993). The Nature Conservancy recognized 55% of North American unionaceans as extinct or imperiled (Master, 1990). Harris and Gordon (1987) considered eighteen of the 69 unionacean species (26%) known or thought to occur in Arkansas (Gordon et al., 1980) as rare and/or endangered within the state.

Approximately 10 years have passed since Harris and Gordon (1987) reviewed the status of the Arkansas unionacean fauna, and substantial additional distributional and relative abundance data for Arkansas unionaceans have been obtained. In this paper, the purpose is to provide a comprehensive review of the conservation status for all native unionacean bivalves known to occur in Arkansas.

Materials and Methods

The distribution and population structure of unionacean aggregrations (= mussel beds) within approximately 1375 kilometers (km) (860 river miles) and 182 impounded or oxbow km (114 river miles) were determined during large river surveys conducted from 1991-1996. Surveys were conducted in the Black, Cache, Current, Little Missouri, Ouachita, Saline, Spring, St. Francis, Strawberry, and White rivers, the Lake Ozark and Lake Dardanelle pools of the Arkansas River, Blue Mountain Lake and Lake Chicot (Harris et al., 1993). In addition, the authors have performed numerous smaller scale surveys (with reports) during the past 10 years further elucidating the distribution, relative abundance and habitat requirements of Arkansas unionaceans.

Survey methods included primarily Hookah diving as detailed in Harris et al. (1993), Rust (1993), and Christian (1995) and/or snorkeling techniques (Harris and Gordon, 1988). Qualitative, semi-quantitative, and quantitative sampling protocols have all been utilized (Rust, 1993; Christian, 1995; and Stoeckel et al., 1996).

The distribution and status of species discussed in this paper were derived by plotting site occurrences and reviewing abundance data, relative or quantitative, for data included in Harris and Gordon (1987) and those obtained in the ensuing 10 years. Taxa discussed in this paper are divided into two groups: (1) Federal Listed Species, and (2) Other Species of State Concern. A third category, Species Under Federal Review, utilized in Harris and Gordon (1987), has been dropped from this paper because the U.S. Fish and Wildlife Service (1996) has revised its animal notice of review categories. Former Category 2 and 3 candidate listings have been discontinued, and Category 1 species are now listed as taxa proposed to be listed as endangered (PE) or taxa proposed to be listed as threatened (PT). There are no mussel taxa that occur in Arkansas which have been included in the most recent review of plant and animal taxa that are candidates for listing as endangered or threatened species (U.S. Fish and Wildlife Service 1996).

The Nature Conservancy utilizes its central conservation databases and the network of natural heritage programs to determine a global conservation rank for mussels (C. Osborne, pers. comm.) Global Rank categories used by The Nature Conservancy are: G1 - critically imperiled globally because of extreme rarity (five or fewer occurrences or very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction; G2 imperiled globally because of rarity (six to 20 occurrences or few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction; G3 - either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g. a single western state, a physiographic region in the East) or because of other factors making it vulnerable to extinction throughout its range, in terms of occurrences, a range of 21 to 100; G4 - apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery; G5 - demonstrably secure globally, though it may be quite rare in parts of its range, especially at the periphery; GH - of historical occurrence throughout its range, i.e. formerly part of the established biota, with the expectation that it may be rediscovered.

Conservation status categories utilized in this paper follow Williams et al. (1993) and are defined as: Endangered (E) - a species or subspecies in danger of extinction throughout all or a significant portion of its range; Endangered, probably extirpated (EX) - a species or subspecies that is probably extinct from the geographic unit being considered; Threatened (T) a species or subspecies that is likely to become endangered throughout all or a significant portion of its range; Special Concern (SC) - a species or subspecies that may become endangered or threatened by relatively minor disturbances to its habitat, and deserves careful monitoring of its abundance and distribution; Undetermined (U) - a species or subspecies whose historic and current distribution and abundance has not been evaluated in recent years; Currently Stable (CS) - a species or subspecies whose distribution and abundance may be stable, or it may have declined in portions of its range but is not in need of immediate conservation management actions.

Nomenclature follows Turgeon et al. (1988) as modified by Williams et al. (1993). Posey et al. (1996) recognized 74 taxa of mussels to have occurred historically within Arkansas.

Results

Table 1 summarizes the conservation status assigned to rare Arkansas mussels by the U.S. Fish and Wildlife Service (1996), The Nature Conservancy (C. Osborne, pers. comm.), Williams et al. (1993), and Harris and Gordon (1987). The table and following text address federally listed endangered and threatened species (listed alphabetically) first, followed by species of state concern that are segregated by conservation status listing (i.e. endangered, threatened, special concern, currently stable). The revised conservation status listing for Arkansas unionacean species as proposed in this paper is found in the last column of Table 1. All Arkansas unionaceans listed by Posey et al. (1996) but not listed in Table 1 are considered to be currently stable (CS).

Federal Listed Species

Arkansia wheeleri Ortmann and Walker, 1912 - Ouachita rock-pocketbook. Distribution: Figure 1. STATUS: National and State -Endangered.

The U.S. Fish and Wildlife Service (1991) listed the Ouachita rockpocketbook as endangered (without critical habitat), and a recovery plan for *Arkansia wheeleri* has been prepared (U.S. Fish and Wildlife Service 1994). Harris and Gordon (1987) suggested the Ouachita rock-pocketbook might have been extirpated within Arkansas. Clarke (1987) subsequently found a small number of individuals in an 8-km reach of Little River running east from the Oklahoma - Arkansas state line, Little and Sevier counties. Clarke (1987) estimated the entire Little River population to be fewer than 100 individuals. Posey et al. (1996) rediscovered the Ouachita rock-pocketbook in the Ouachita River (River Mile 334.0) downstream of Camden, Ouachita County, Arkansas. The Ouachita rock-pocketbook had not been recorded alive from the Ouachita River since Wheeler (1918), and its discovery downstream of Camden indicates the species can occur in larger rivers than previously documented. The Ouachita rock-pocketbook remains extremely rare globally and within Arkansas.

Epiobasma florentina curtisi (Utterback, 1916) - Curtis pearlymussel. Distribution: Harris and Gordon (1987). STATUS: National and State Endangered.

No additional data have been acquired since Harris and Gordon (1987). Its state status is continued as endangered rather than extirpated because the species remains extant in the Little Black River system in Missouri.

Epioblasma turgidula (Lea, 1858) - turgid blossom. Distribution: Harris and Gordon (1987). STATUS: National and State Extirpated.

No additional data have been acquired since Harris and Gordon (1987) who considered this species endangered in Arkansas. The status within Arkansas is changed to possibly extinct in agreement with Harris and Gordon (1990) and Williams et al. (1993).

Lampsilis abrupta (Say, 1831) - pink mucket Distribution: Figure 2. STATUS: Federal - Endangered, State - Threatened.

Table 1. Summary of conservation status rankings for Arkansas' rare unionacean bivalves.

Scientific Name common name	TNC Global Rank	Federal Status	Williams et al. 1993	Harris and Gordon 1987	Revised AR Status
Arkansia wheeleri Ouachita rock pocketbook	G1	E	E	EX	E
Epioblasma florentina curtisi Curtis' pearly mussel	G1	E	E	E	E
Epioblasma turgidula turgid blossom	GH	E	EX	E	EX
Lampsilis abrupta pink mucket	G2	E	E	E	T
Lampsilis powelli Arkansas fatmucket	G1G2	T	T	T	T
Lampsilis streckeri speckled pocketbook	G1Q	E	E	U	E
Potamilus capax fat pocketbook	G1	E	E	E	T
Quadrula fragosa winged mapleleaf	G1	E	E	NL	E
Alasmidonta viridis slippershell	G4	NL	SC	NL	E
Cumberlandia monodonta spectaclecase	G2G3	NL	T	EX	E
Epioblasma triquetra snuffbox	G3	NL	T	E	E
Potamilus alatus pink heelsplitter	G5	NL	CS	E	E
Simpsonaias ambigua salamander mussel	G3	NL	SC	T	E
Lampsilis rafinesqueana Neosho mucket	G2	SS	T	T	T
Leptodea leptodon scaleshell	G1G2	SS	E	T	T
Quadrula apiculata southern mapleleaf	G5	NL	CS	NL	T
Anodonta suborbiculata flat floater	G5	NL	CS	SC	SC
Cyprogenia aberti western fanshell	G2	NL	T	SC	SC
Obovaria iacksoniana southern hickorynut	G2G3	NL	SC	NL	SC
Quadrula C. cylindrica rabbitsfoot	G3	NL	T	SC	SC
Toxolasma lividus purple lilliput	G1G2Q	NL	SC	NL	SC
Villosa arkansasensis Ouachita creekshell	G2	NL	SC	NL	SC
Pleurobema pyramidatum pyramid pigtoe	G2	NL	T	SC	CS

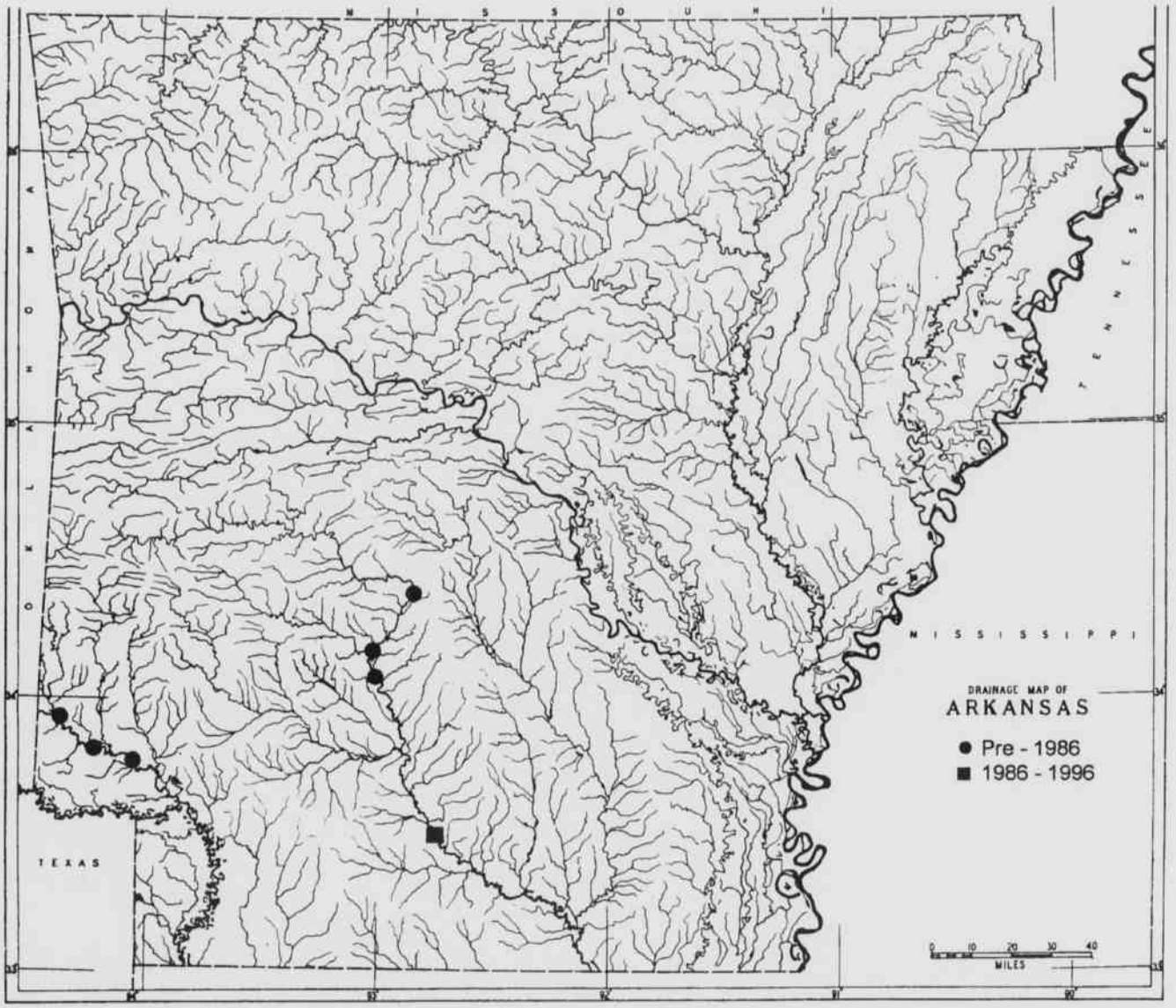

Fig. 1. Distribution of *Arkansia wheeleri*.

Harris and Gordon (1987) discussed the systematics of the pink mucket, as *Lampsilis orbiculata* (Hildreth, 1828), which Turgeon et al. (1988) suppressed in favor of *Lampsilis abrupta* (Say, 1831). Rust (1993) encountered 31 live pink muckets from 19 of 48 (39.6%) unionacean aggregations in an approximately 175-km reach (River Miles 50.5 - 161.5) of the Black River. The maximum number of pink muckets sampled from an individual Black River unionacean aggregation (River Mile 151.1) was five which was 1.3% of total mussels examined from the bed and yielded a population estimate of 500+/-102. Rust (1993) also found 11 pink mucket specimens from four of six sites (66.7%) in approximately 18 km of the Spring River. Again, the maximum number of pink muckets encountered in a single aggregation was five, which was 1.5% of total unionaceans examined from the aggregation and yielded a population estimate of 121+/-24. Posey (1997) encountered a total of nine pink musket individuals at eight sites in the Ouachita River. Christian (1995) found a single pink mucket at four of 51 sites (7.8%) examined in the White River, and a single pink mucket was tentatively identified from the Cache River. Additional small scale surveys for the pink mucket in the White River (Harris, 1987, 1989a, 1989b, 1989d, 1990c, 1994c, 1995, 1997c) yielded individuals at the White River downstream

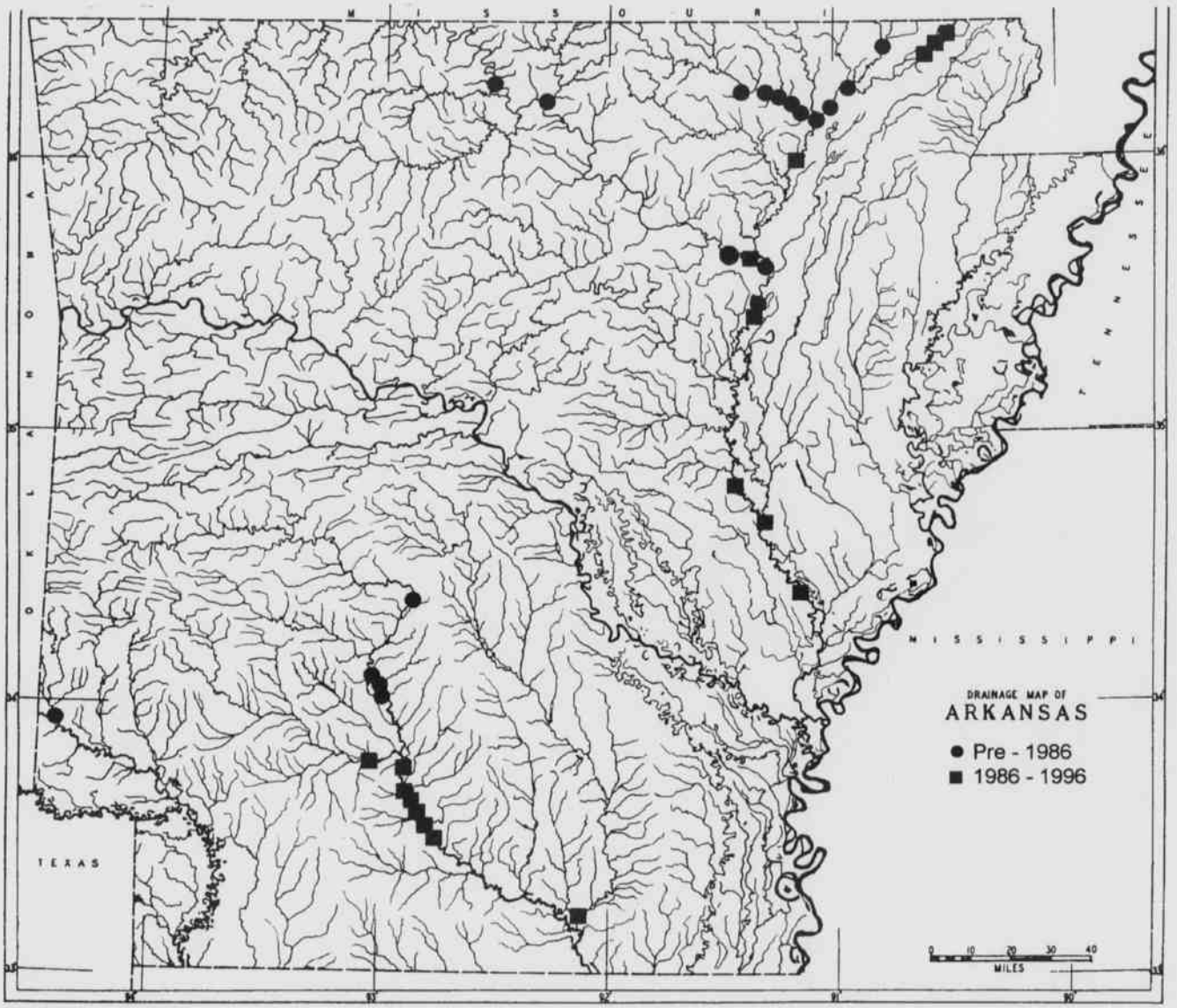

Fig. 2. Distribution of *Lampsilis abrupta*.

of Oil Trough, the White River near Old Grand Glaise, and the White River at DeValls Bluff.

Lampsilis abrupta population numbers appear stable but low in the Black, Ouachita, and Spring rivers. Gravel dredging, reservoir discharges and maintenance of existing navigation channels continue as threats to the species. The White River Navigation project has been reauthorized (Corps of Engineers, 1996) and, if constructed and maintained, poses a potential threat to the continued existence of the pink mucket within the White River, Arkansas. However, at the present time, the authors feel that revising the conservation status of the pink mucket within Arkansas to threatened is appropriate.

Lampsilis powelli (Lea, 1852) - Arkansas fatmucket. Distribution: Figure 3. STATUS: National and State - Threatened.

Lampsilis powelli is an Arkansas endemic which Harris and Gordon (1987) listed as threatened within Arkansas. Harris and Gordon (1988) performed the status survey for the Arkansas fatmucket, and the species was subsequently listed as threatened by the U.S. Fish and Wildlife Service (1990). A recovery plan has been prepared for the Arkansas

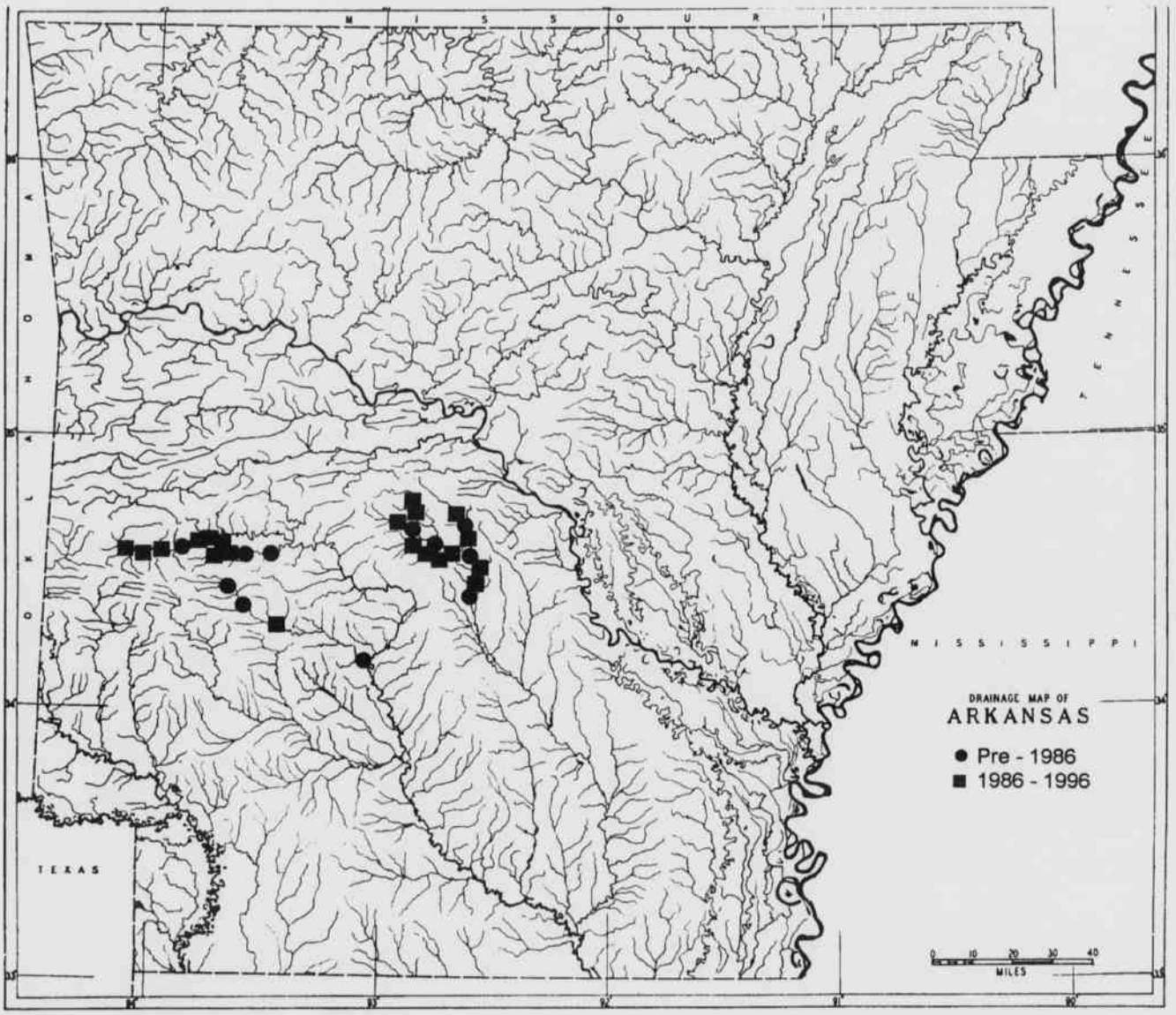

Fig. 3. Distribution of *Lampsilis powelli*.

fatmucket (U.S. Fish and Wildlife Service, 1992). Additional surveys and habitat characterizations are reported by Brown and Brown (1989), Burns & McDonnell (1992a, 1992b), Harris (1989c, 1991a, 1994a), and Harris et al. (1992).

The Arkansas fatmucket is known to occur in the Caddo River upstream and downstream of DeGray Lake, upper Ouachita River and South Fork Ouachita River upstream of Lake Ouachita, and the Alum, Middle, North and South forks of the Saline River, as well as the mainstem Saline River downstream to approximately the boundary of the Interior Highlands and Gulf Coastal Plain. Surveys performed by Burns & McDonnell (1992a, 1992b) documented the presence of *Lampsilis powelli* in the North and South forks Saline River and the upper Ouachita River. The three largest Arkansas fatmucket populations occur in the Alum and Middle forks Saline River and the South Fork Ouachita River (5,000-10,000 estimated individuals each) with additional important populations existing in the upper Ouachita River and the mainstem Saline River (1,000-5,000 estimated individuals each) (Burns & McDonnell, 1992b).

Siltation and sedimentation (Harris and Gordon, 1988; Brown and Brown, 1989) and a lack of recruitment (Harris

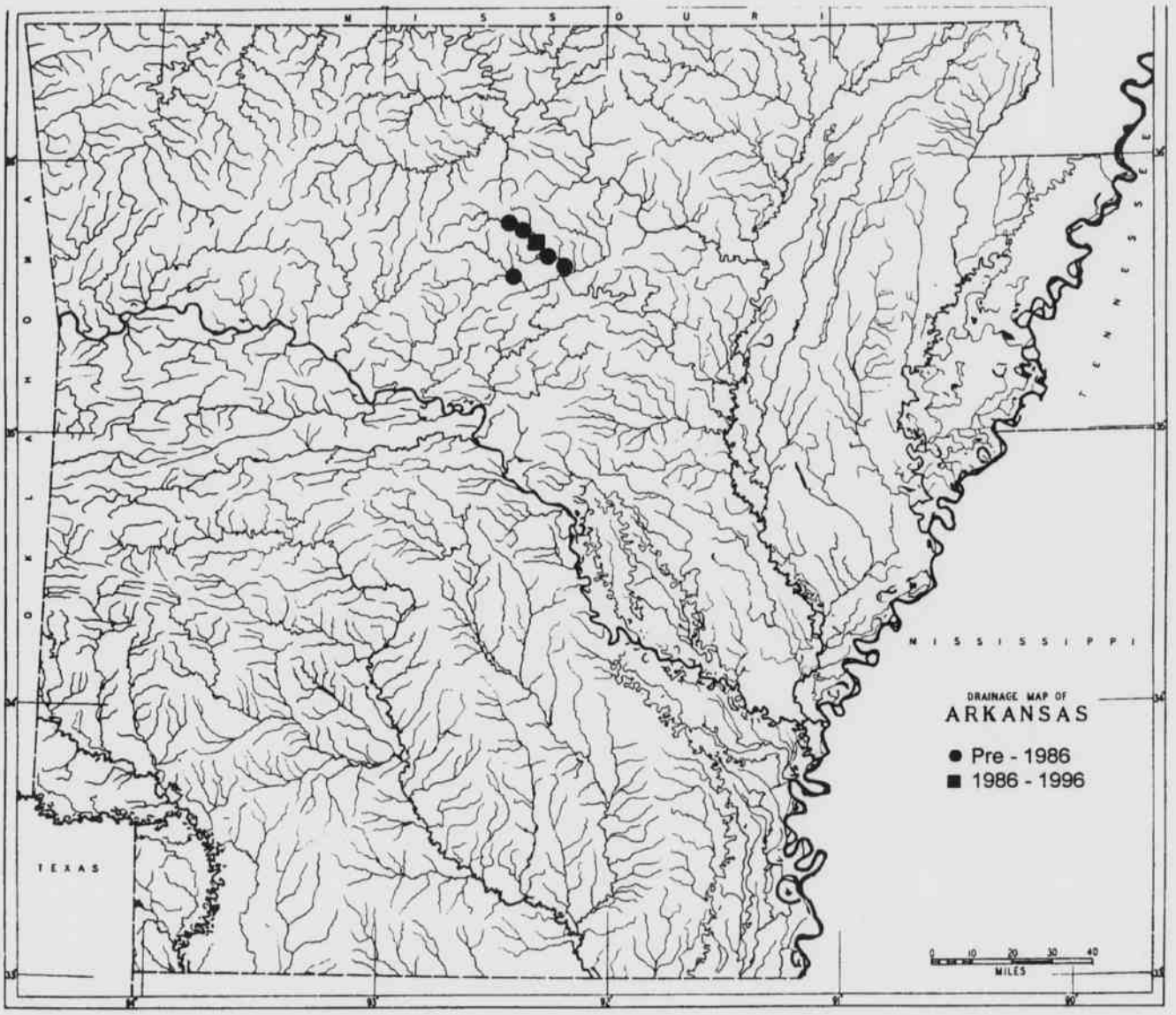

Fig. 4. Distribution of *Potamilus streckeri*.

1994a) have been identified as contributors to the threatened status of this species. *Lampsilis powelli* may have been the most intensively studied unionacean species in Arkansas over the past 10 years.

Lampsilis streckeri Frierson 1927 - speckled pocketbook. Distribution: Figure 4. STATUS: National and State - Endangered.

Harris and Gordon (1987) listed the status of the speckled pocketbook as uncertain because of taxonomic confusion. Clarke (1987) concluded that *Lampsilis streckeri* was a valid taxon with its distribution restricted to approximately 14 km of the Middle Fork Little Red River. The U.S. Fish and Wildlife Service (1989) listed the speckled pocketbook as endangered, and a recovery plan has been prepared (U.S. Fish and Wildlife Service, 1991).

Additional surveys and habitat characterizations were reported by Harris (199lb, 1992a, 1992c, 1993). Harris (1992a) extended the known range of *Lampsilis streckeri* to approximately 19.4 km of the Middle Fork Little Red River and also determined that the speckled pocketbook was successfully inhabiting sandy substrates under slab rock (Harris, 1993).

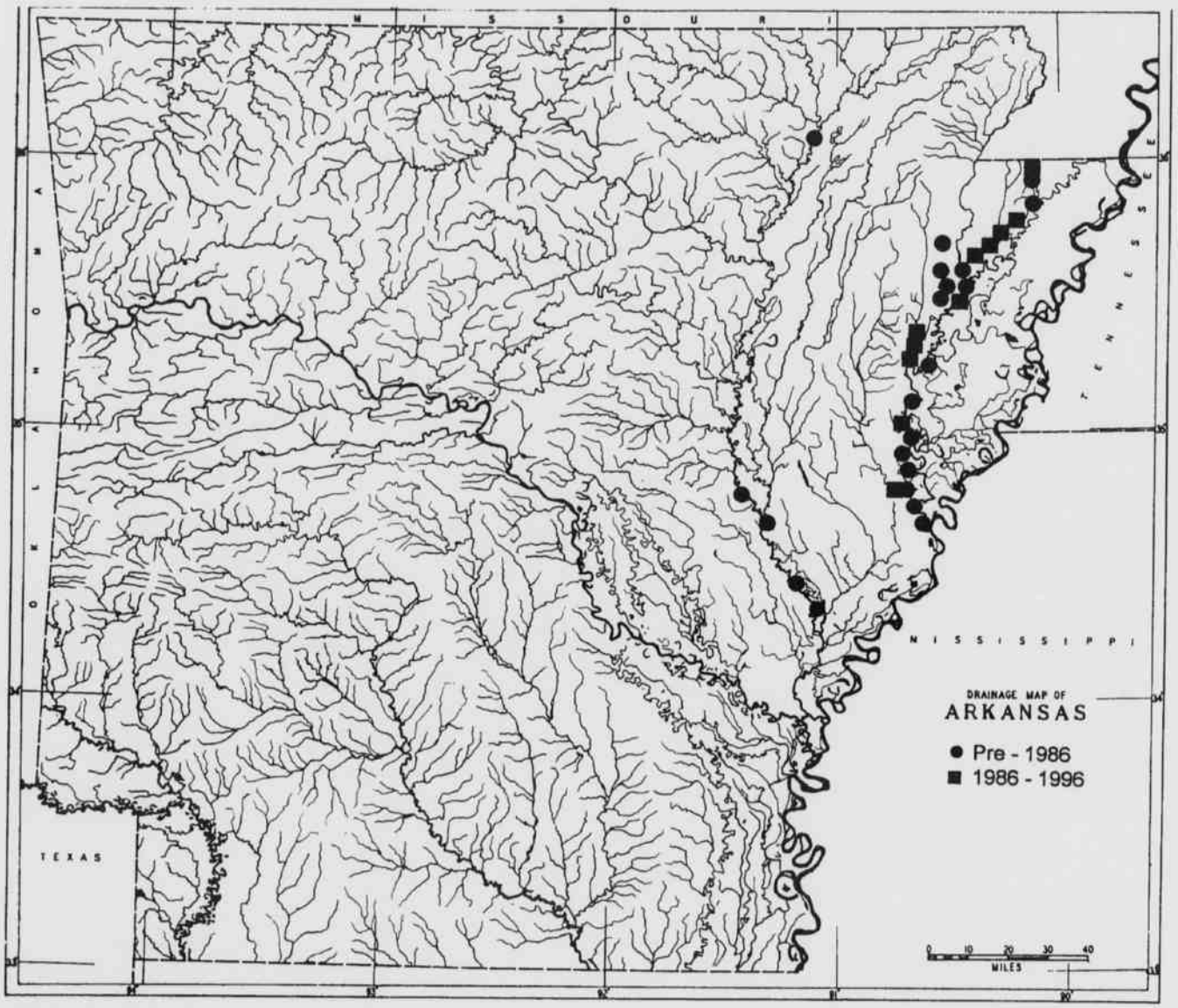

Fig. 5. Distribution of *Potamilus capax*.

Distribution and abundance of the speckled pocketbook has been impacted negatively by alteration of habitat due to impoundment of the Little Red River to form Greers Ferry Reservoir, flood control projects (channelization), instream gravel mining, and timber harvest (Clarke, 1987; U.S. Fish and Wildlife Service, 1992; Harris, 1993).

Potamilus capax (Green, 1832) -fat pocketbook. Distribution: Figure 5. STATUS: Federal - Endangered, State - Threatened.

Since Harris and Gordon (1987), an additional unionacean survey that encompassed 256 sites in the Cache and St. Francis river drainages was completed by Jenkinson and Ahlstedt (1987). This survey targeted many man-made ditches and smaller streams that were not surveyed by Ahlstedt and Jenkinson (1987). Additional small scale surveys for the fat pocketbook have been performed by Harris (1990a, 1990b, 1997a), and Jenkinson (1989) reported the results of a relocation of *Potamilus capax* from a 6.4-km reach of the St. Francis Floodway prior to dredging for flood control. Ahlstedt and Jenkinson (1991) summarized the available information regarding the distribution and abundance of *Potamilus capax* in the St. Francis River system. Thirty-

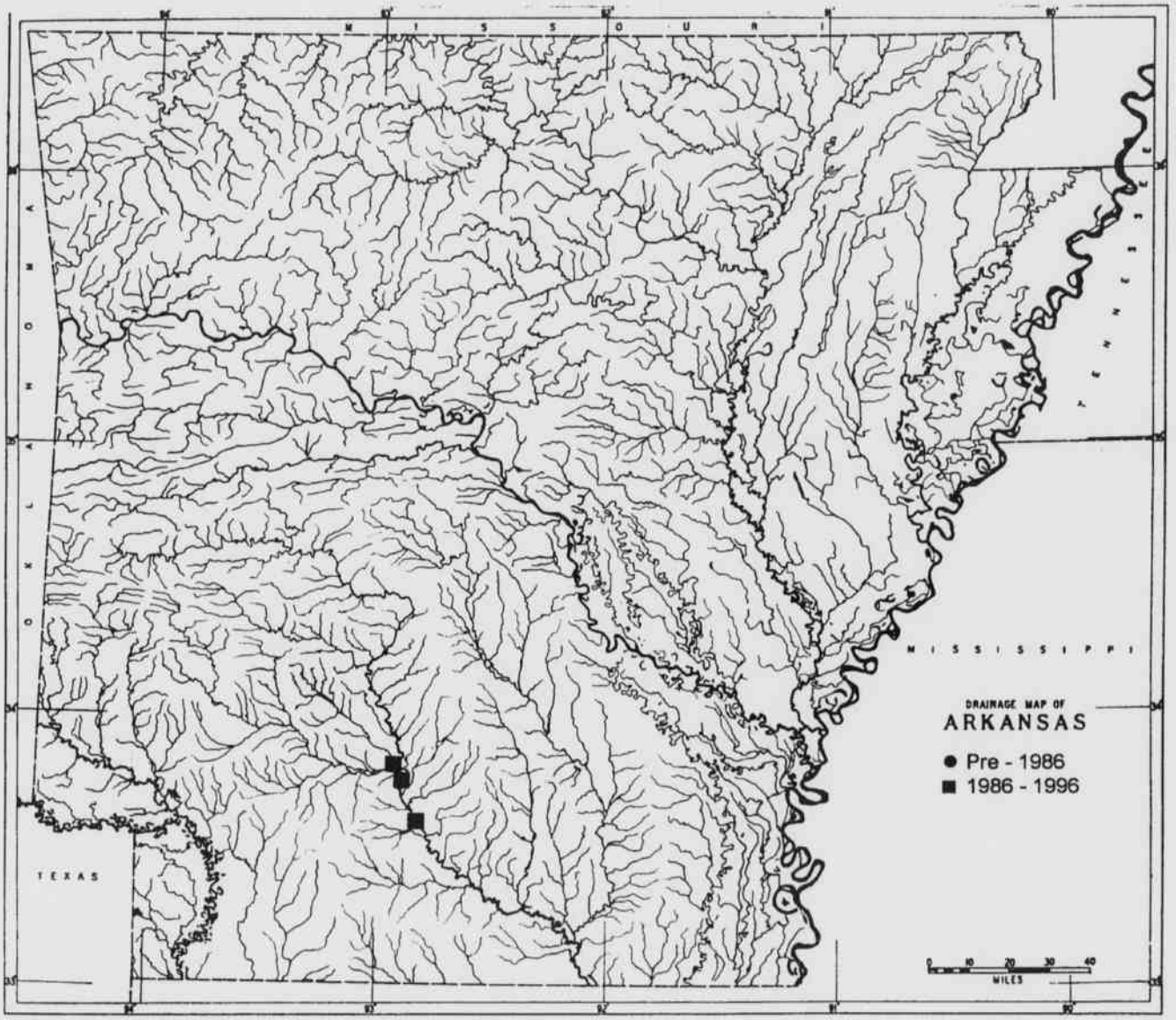

Fig. 6. Distribution of *Quadrula fragosa*.

three fat pocketbook individuals were collected at 10 riverine sites and 109 individuals were found at 14 ditch sites in Arkansas.

Jenkinson and Ahlstedt (1987) found the fat pocketbook in a downstream reach of the L'Anguille River and at many sites within man-made ditches and low order tributanes to the St. Francis floodway. The number of new sites and relative abundance of the fat pocketbook at these sites leads the authors to revise the conservation status of the fat pocketbook within Arkansas from endangered to threatened.

Quadrula fragosa (Conrad, 1835) - winged mapleleaf. Distribution: Figure 6. STATUS: National and State - Endangered.

Posey et al. (1996) recently discovered the presence of the winged mapleleaf within Arkansas where it is known to occur at three sites; two in the Ouachita River upstream of Camden, Ouachita County, and one in the Little Missouri River near its confluence with the Ouachita (Davidson, 1997). A total of seven specimens of *Quadrula frazosa* is known now from Arkansas.

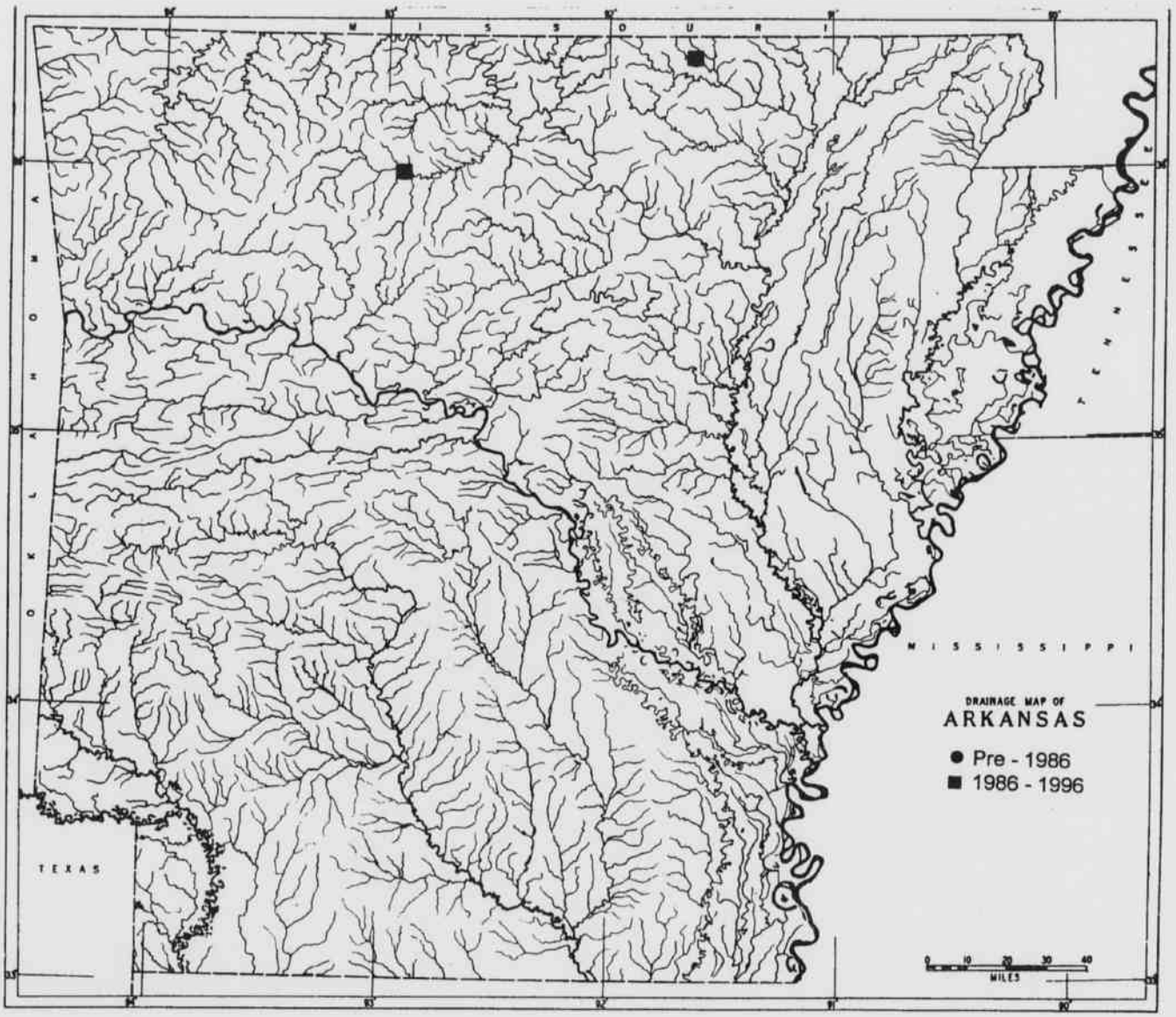

Fig. 7. Distribution of *Alasmidonta viridis*.

Other Species of State Concern

Alasmidonta viridis (Rafinesque, 1820) - slippershell mussel. Distribution: Figure 7. STATUS: State-Endangered.

Meek and Clark (1912) recorded the slippershell mussel from the Buffalo River, and Gordon et al. (1980) listed it (as *Alasmidonta calceolus*) from the Buffalo and White rivers. Harris (1996) found a total of two live and one fresh dead specimens at two of 41 survey sites in the Buffalo River, and Davidson et al. (1997) recorded a single relict specimen from Myatt Creek in the Spring River drainage. This species was not considered for conservation status listing by Gordon and Harris (1987).

Cumberlandia monodonta Say, 1829 - spectaclecase. Distribution: Figure 8. STATUS: State Endangered.

Harris and Gordon (1987, 1990) considered the spectaclecase as possibly extirpated from Arkansas since no live or relict specimens had been recorded since Wheeler (1918). Posey et al. (1996) rediscovered the spectaclecase in the Ouachita River at River Miles 364.1 and 375.1, and each site was represented by a single live individual. Stoeckel et al. (1996) discovered the spectaclecase at a single site in the

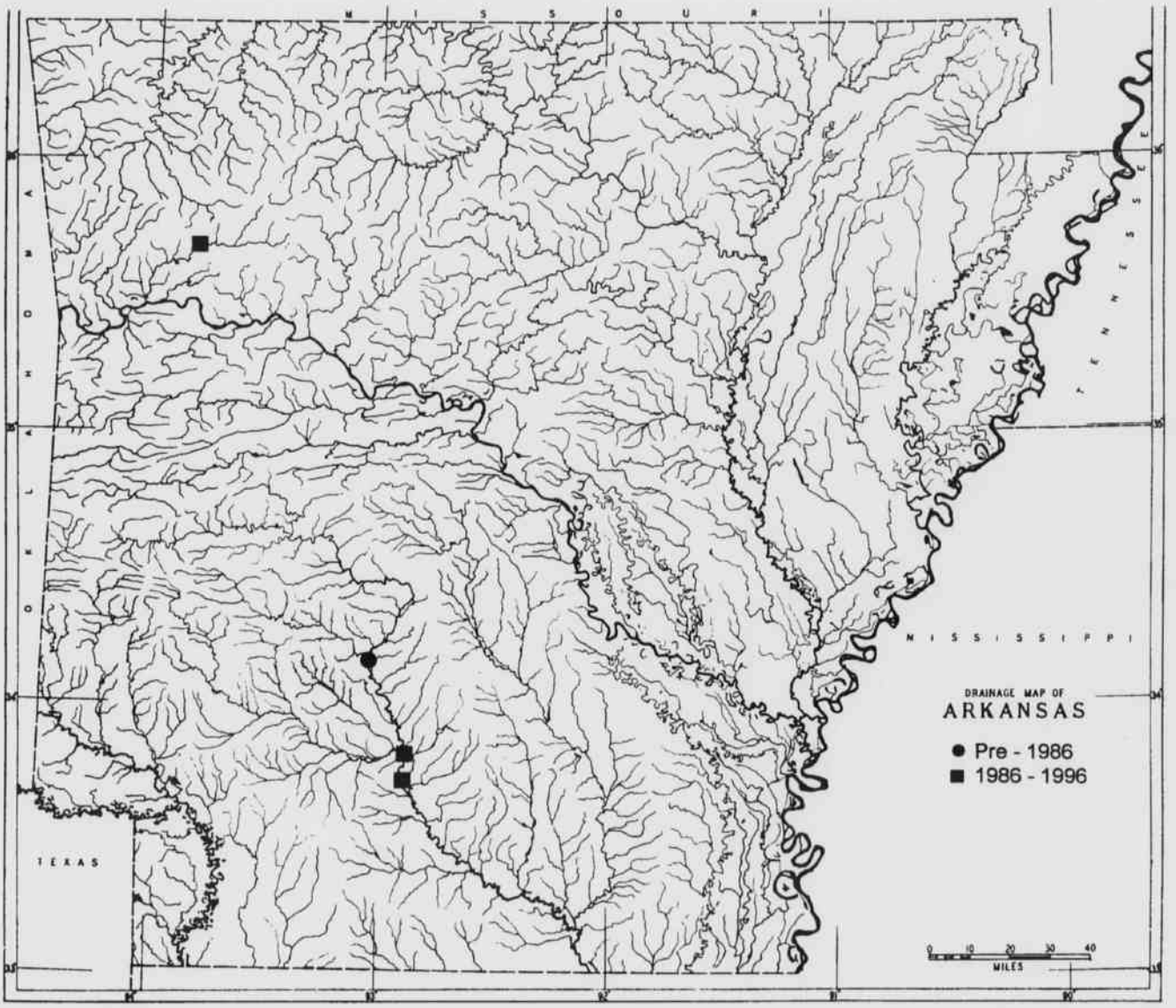

Fig. 8. Distribution of *Cumberlandia monodonta*.

Mulberry River, and this discovery also was represented by a single live individual.

Epioblasma triquetra (Rafinesque, 1920). Distribution: Harris and Gordon (1987). STATUS: State - Endangered

No additional data have been acquired since Harris and Gordon (1987).

Potamilus alatus (Say, 1817) - pink heelsplitter. Distribution: Harris and Gordon (1987). STATUS: State - Endangered.

No additional data have been acquired since Harris and Gordon (1987).

Simpsonaias ambigua (Say, 1825) - salamander mussel. Distribution: Harris and Gordon (1987). STATUS: Endangered.

No additional data have been acquired since Harris and Gordon (1987). Originally listed as threatened within Arkansas by Harris and Gordon (1987), the lack of additional sites or specimens in the ensuing 10 years prompts revision of the conservation status to endangered.

Lampsilis rafinesqueana Frierson, 1927 - Neosho musket. Distribution: Harris and Gordon (1987). STATUS: State - Threatened.

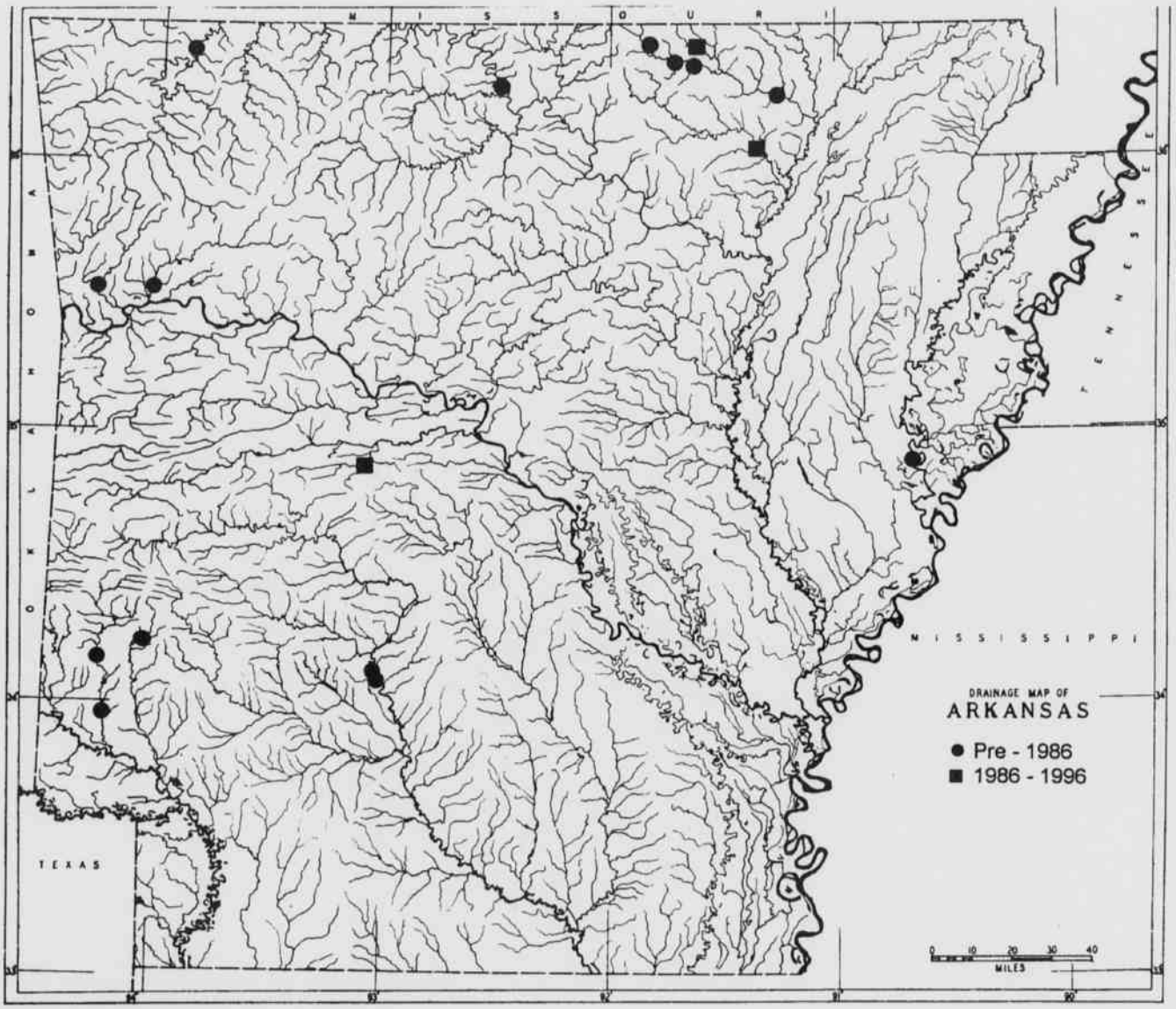

Fig. 9. Distribution of *Leptodea leptodon*.

The distribution of this species remains as reported in Harris and Gordon (1987). Harris (199ld) performed a small scale survey for the Neosho mucket in the Illinois River near the Arkansas - Oklahoma state line, and three live specimens were found. A status survey for the Neosho mucket within Arkansas was performed by Harris (1997b), and the species was found to be locally abundant in the mainstem of the Illinois River. The Neosho mucket was present at 18 of 22 sites searched, and 148 specimens were found which represented 11.9% of the unionaceans examined.

Leptodea leptodon (Rafinesque, 1820) - scaleshell. Distribution: Figure 9. STATUS: State - Threatened.

Since Harris and Gordon (1987), the scaleshell has been found at single sites in the South Fork Fourche La Fave River (Harris 1992b) and Myatt Creek (Davidson et al., 1997). Recent collections by authors JLH and ADC yielded two specimens (one live, one dead) from two sites in the Strawberry River. The species remains widely distributed but rare within Arkansas.

Quadrula apiculata (Say, 1829) - southern mapleleaf.

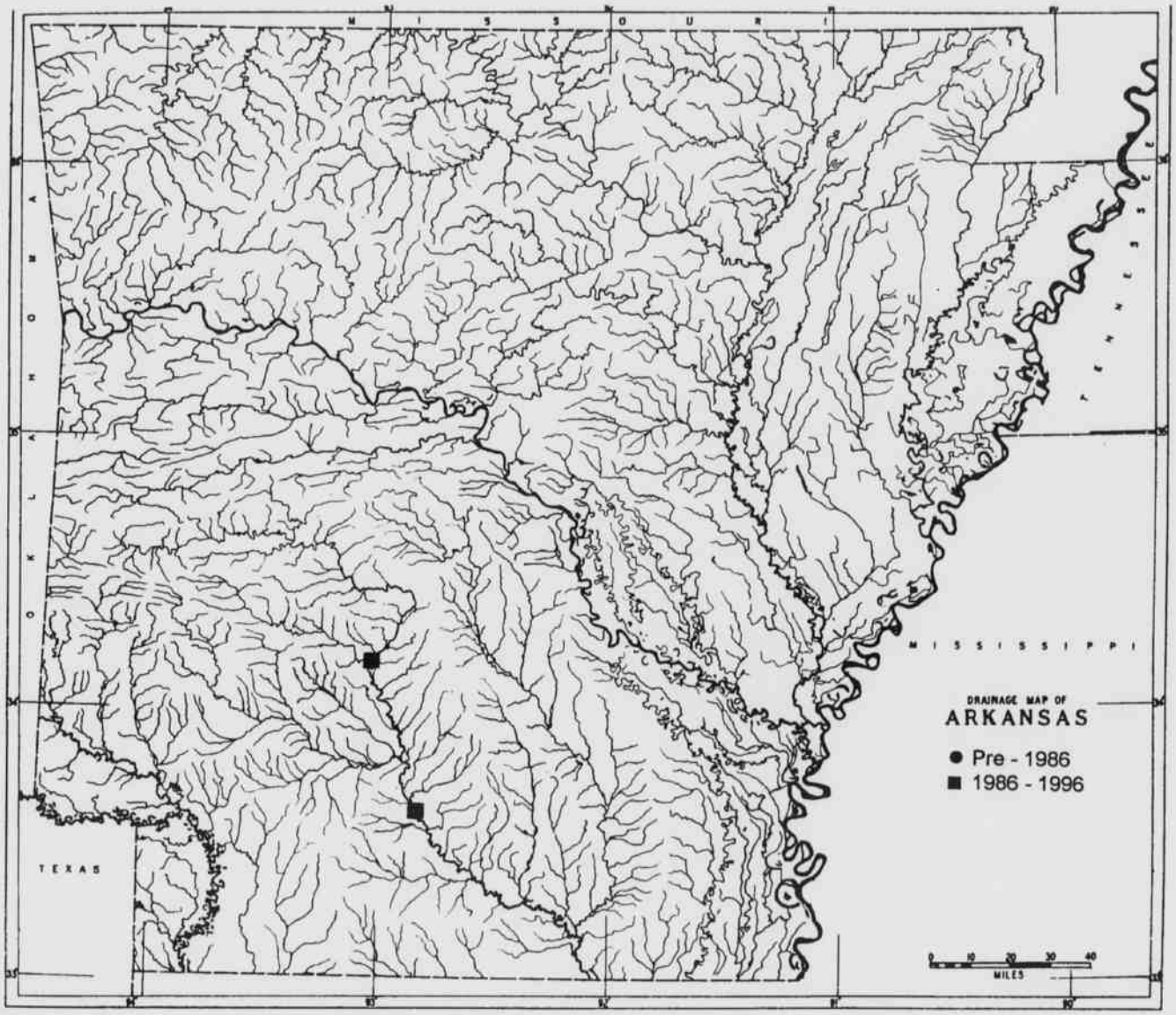

Fig. 10. Distribution of *Quadrula apiculata*.

Distribution: Figure 10. STATUS: Threatened.

Posey et al. (1996) reported that the southern mapleleaf was collected at multiple sites in the Ouachita River between River Miles 353.7 and 221.2. The species may also occur in the Ouachita River (Wheeler, 1918) and Lake Chicot (Cooper, 1984). A specimen referrable to *Quadrula apiculata* was recently collected in the White River near DeValls Bluff. The conservation status of this species within Arkansas was not discussed by Harris and Gordon (1987).

Anodonta suborbiculata Say, 1831 -flatfloater. Distribution: Figure 11. STATUS: Special Concern.

Ahlstedt and Jenkins (1991) collected five specimens of the flat floater from three river sites and 18 specimens from six ditch sites within the St. Francis River system in Arkansas. Davidson (1997) found this species to be widespread but relatively uncommon in Ozark Lake and Lake Dardanelle within the Arkansas River Navigation System. Harris (1989b, 1991c) and Harris et al. (1993) found the flat floater to comprise a minor portion of the unionacean community at specific sites in the Ouachita River, Lake Dardanelle, and Lake Chicot, respectively. Surveys of oxbows, backwaters, and larger river systems should contin-

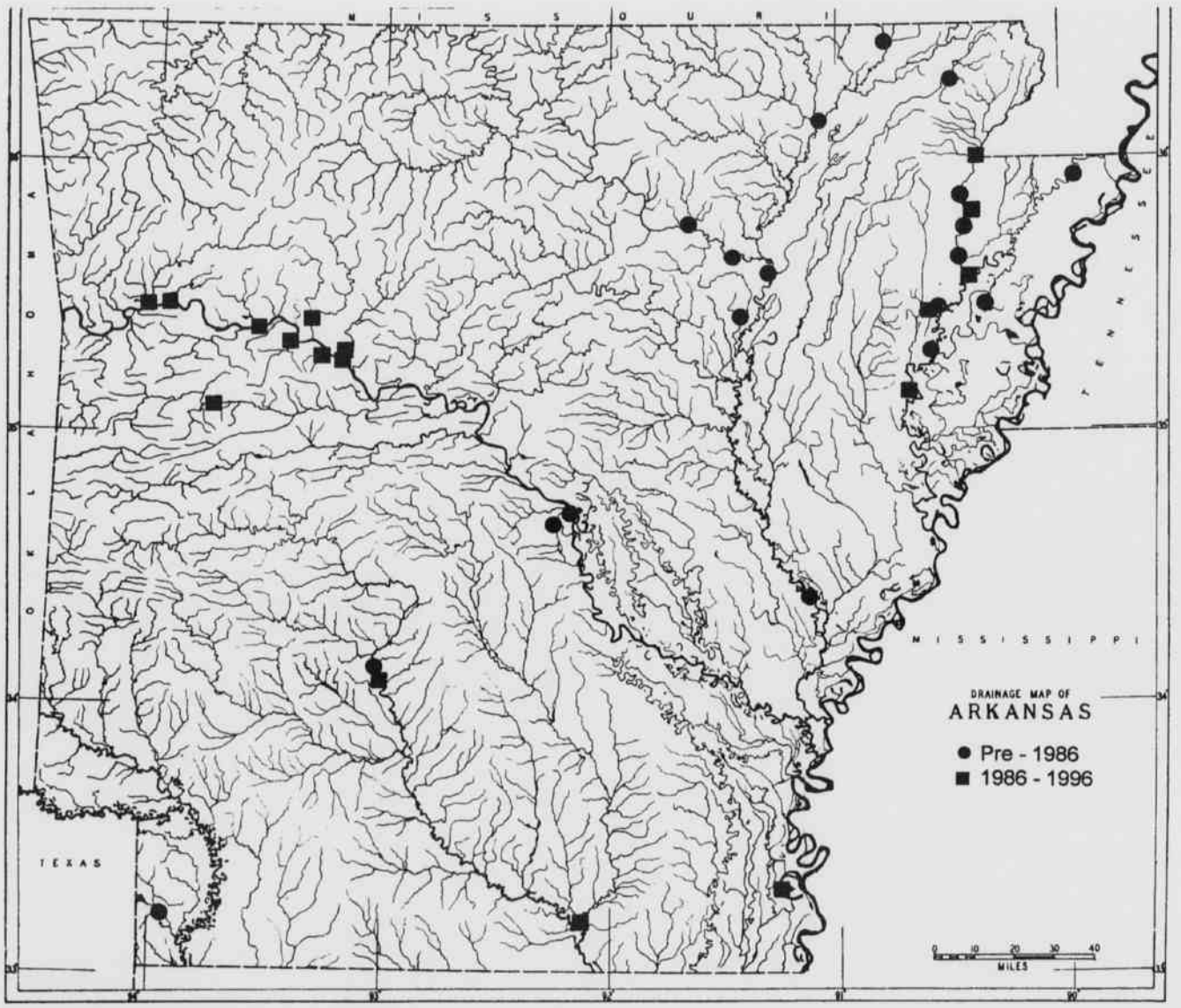

Fig. 11. Distribution of *Anodonta suborbiculata*.

ue to yield additional localities where this species exists.

Cyprogenia aberti (Conrad, 1850) - western fanshell. Distribution: Figure 12. STATUS: State - Special Concern.

Christian (1995) found *Cyprozenia aberti* at three of 51 unionacean aggregations in the White River, but the western fanshell was not found in the Cache River. Rust (1993) found the western fanshell at seven of 48 sites sampled in the Black River where it was locally abundant, comprising 5 - 10 percent of the total unionaceans encountered at River Miles 72.9 and 75.3. Also, Rust (1993) determined that the western fanshell composed 4.4 - 10.1 percent of the total unionacean community at three major aggregations in the Spring River. Posey (1997) found the western fanshell at five of 61 unionacean aggregations in the Ouachita River, and a total of seven live individuals was examined. Additional sites for *Cyrogenia aberti* were located by Harris and Gordon (1988) and Burns & McDonnell (1992b) in the Ouachita and Saline rivers, Ahlstedt and Jenkinson (1991) in the St. Francis River drainage, Davidson (1997) in the Little Missouri River, and Harris (1996) in the Buffalo River. Also, the western fanshell has been found at nine of 24 sites during recent surveys of the Strawberry River. This species

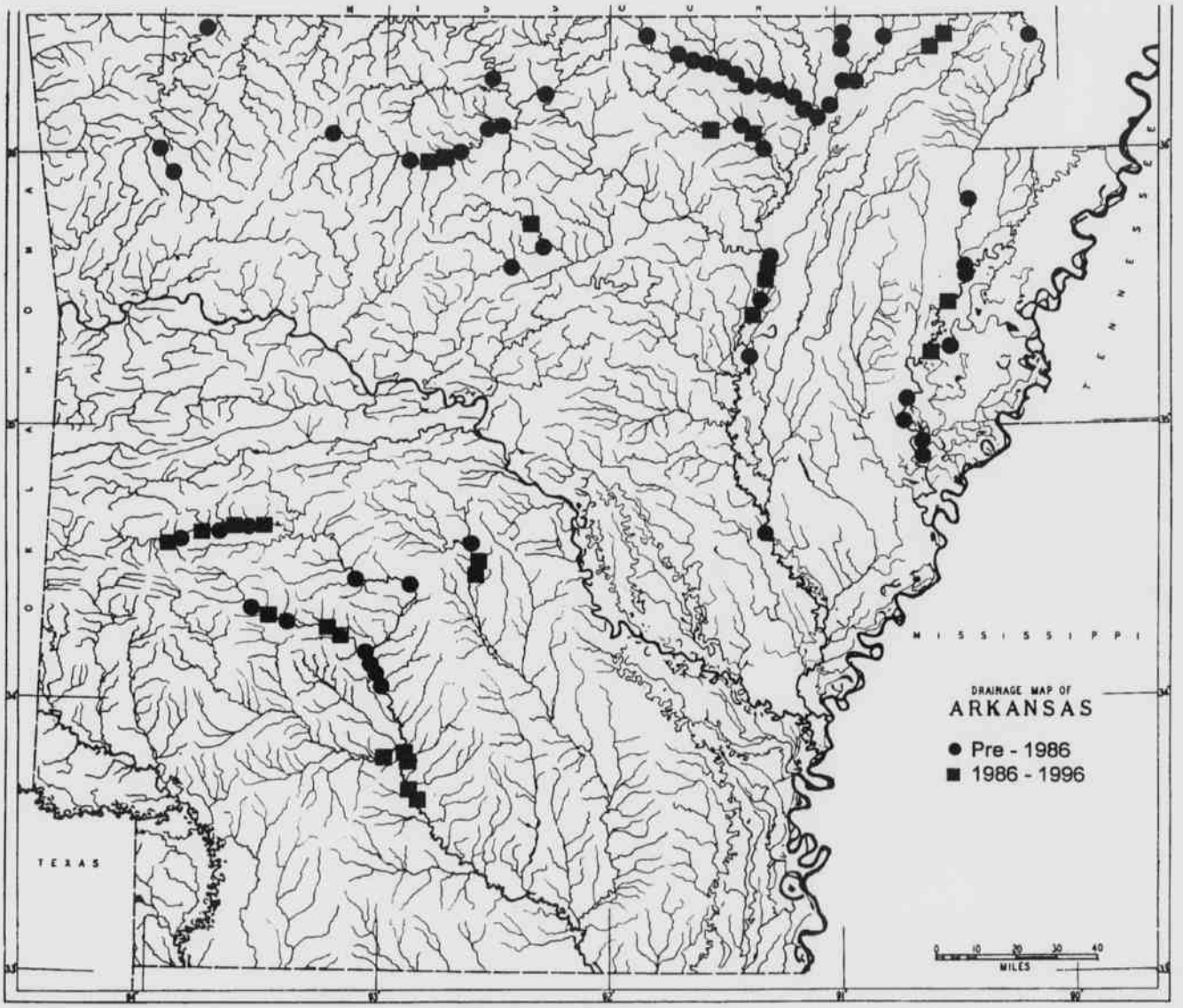

Fig. 12. Distribution of *Cyprogenia aberti*.

is widely distributed within Arkansas, can be locally abundant, but generally is found in relatively low numbers in high quality riverine systems.

Obovaria jacksoniana (Frierson, 1912) - southern hickorynut. Distribution: Figure 13. STATUS: State - Special Concern.

Harris and Gordon (1988), Burns & McDonnell (1992b), and Davidson (1997) found additional localities where the southern hickorynut survives in the Ouachita River system. Harris (1992b) collected a single individual from the South Fourche La Fave River (Arkansas River system), and ADC and JLH found the southern hickorynut at two sites in the Strawberry River (White River system). The southern hickorynut is widely distributed but nowhere abundant, and it deserves to be listed as of special concern.

Quadrula cylindrica cylindrica (Say, 1917) - rabbitsfoot. Distribution: Figure 14. STATUS: State-Special Concern.

Harris and Gordon (1988), Harris (1989c), Burns & McDonnell (1992a, 1992b), Davidson (1997), and Posey (1997) have documented numerous additional localities for this species within the Ouachita River system. Rust (1993), and Christian (1995) have documented numerous addition-

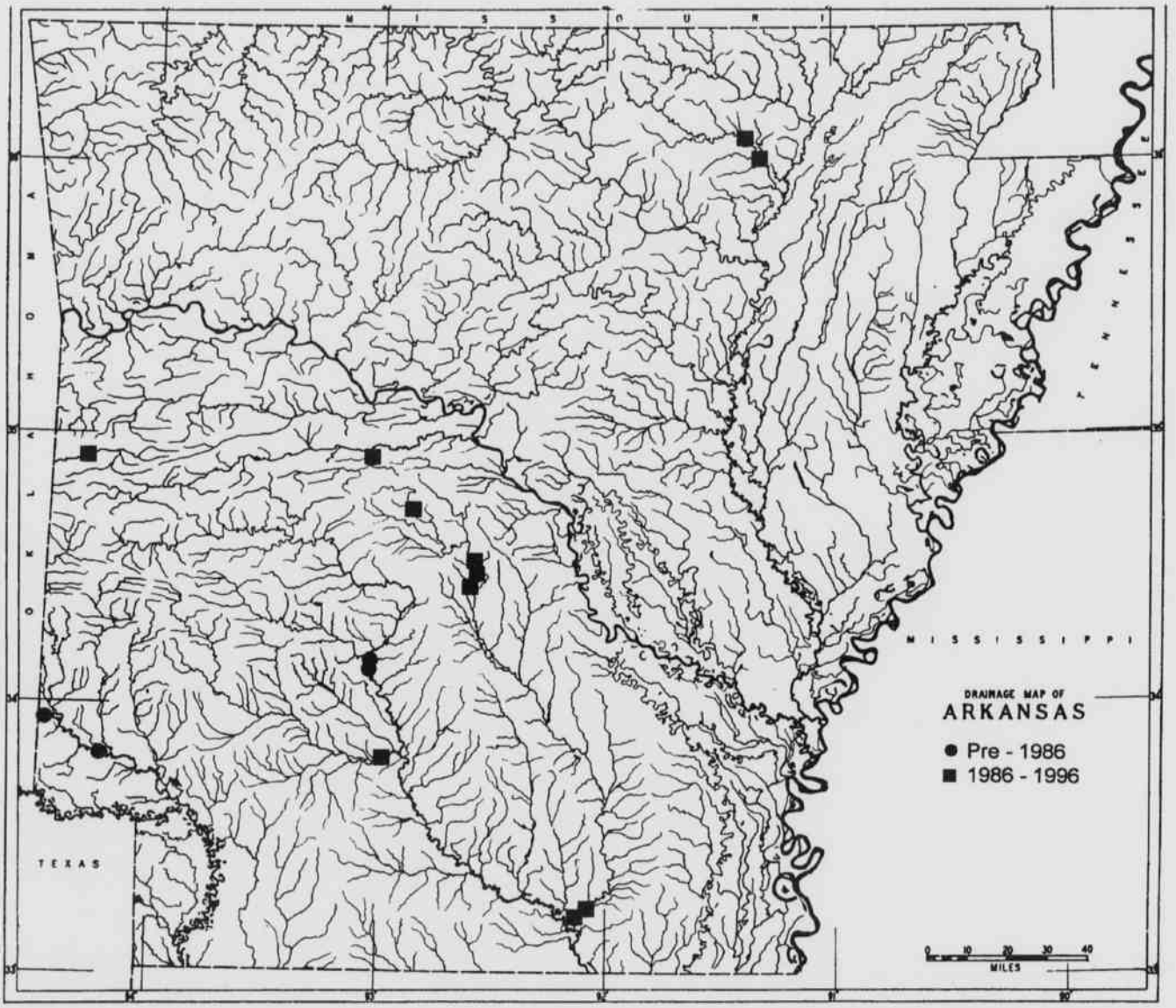

Fig. 13. Distribution of *Obovaria jacksoniana*.

al localities for this species within the White river drainages. Due to relatively low population numbers, this species is considered of special concern within Arkansas.

Toxolasma lividus (Rafinesque, 1831) - purple lilliput. Distribution: Figure 15. STATUS: State - Special Concern.

Harris and Gordon (1988), Burns & McDonnell (1992a, 1992b), and Davidson (1997) discovered the majority of new sites for this diminutive, headwater species, all from the Ouachita River system. Harris (1992b) found two specimens in the South Fourche La Fave River, Harris (1994b) discovered a single specimen in the Poteau River and Harris (1997b) collected the purple lilliput at three sites in the Illinois River. The conservation status of this species was not addressed by Harris and Gordon (1987). Its relatively low population numbers dictate that it be considered of special concern within Arkansas.

Villosa arkansasensis (I. Lea, 1862) - Ouachita creekshell. Distribution: Figure 16. STATUS: State - Special Concern.

Harris and Gordon (1988) and Burns & McDonnell (1992a, 1992b) listed the majority of new occurrences for this headwater species whose center of distribution closely parallels that of the southern hickorynut in Arkansas. Three

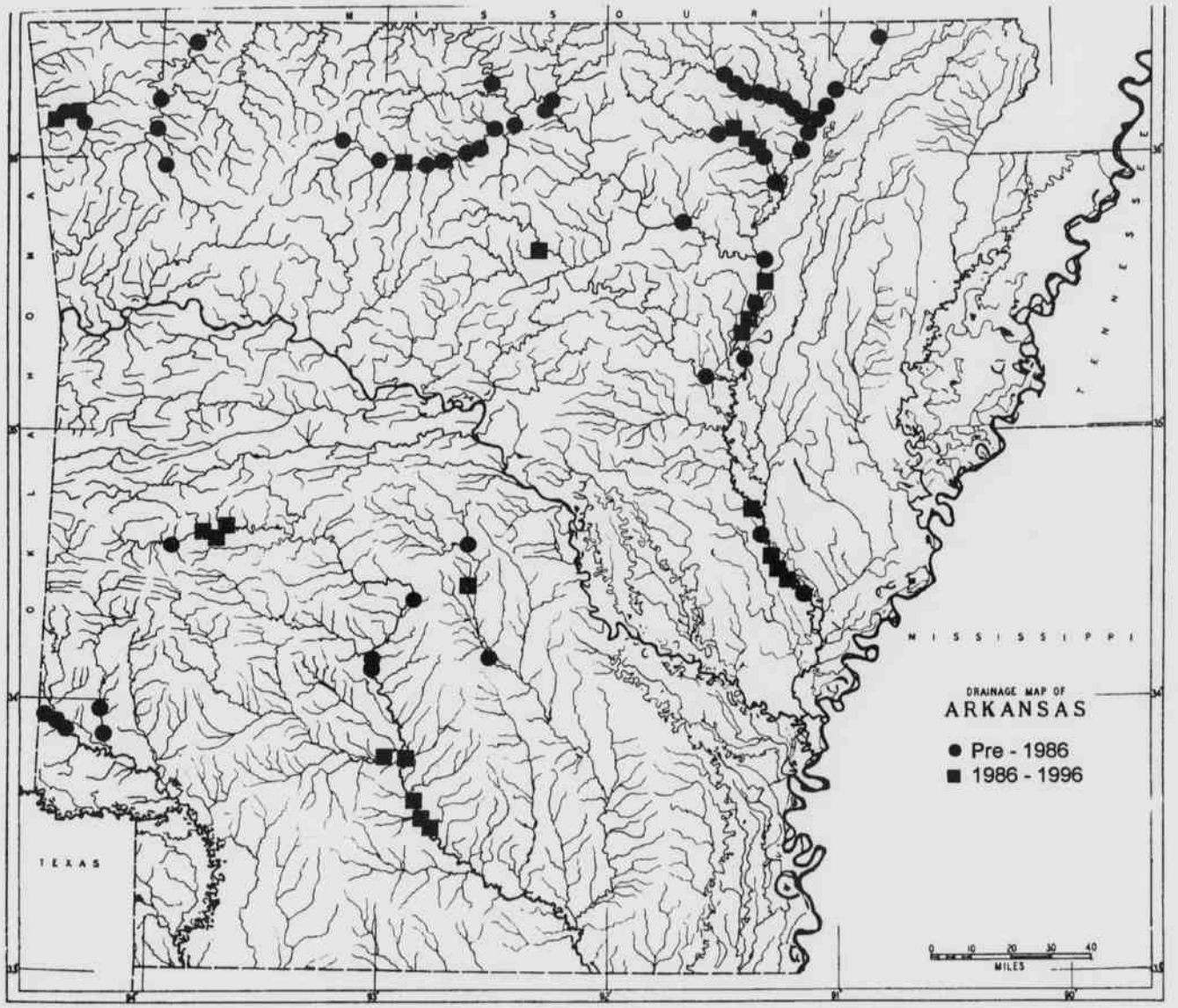

Fig. 14. Distribution of *Quadrula cylindrica cylindrica*.

specimens were collected at three sites in the Poteau River (Harris, 1994b). The conservation status of this species was not addressed by Harris and Gordon (1987). Its relatively low population numbers dictate that it be considered of special concern within Arkansas.

Pleurobema pyramidatum (I. Lea, 1840) - pyramid pigtoe. Distribution: Figure 17. STATUS: State - Currently Secure.

Distribution and relative abundance data acquired by Davidson (1997) and Posey (1997) for the Little Missouri, Ouachita and Saline rivers indicate the pyramid pigtoe is a widely distributed and often numerically dominant species within these drainages. In the Ouachita River below the confluence with the Little Missouri River, Posey (1997) located the pyramid pigtoe in 44 of 61 unionacean aggregrations sampled, and the 3445 specimens examined represented 14.7% of the total unionaceans sampled. From the confluence with the Little Missouri River (River Mile 377) downstream to River Mile 327 (approximately 25 river miles downstream of Camden, AR), the pyramid pigtoe represented 5.3 - 53.3 percent (mean = 27.0) of the unionacean community within 23 aggregations quantitatively sampled (Posey, 1997). Ahlstedt and Jenkinson (1991) have summa-

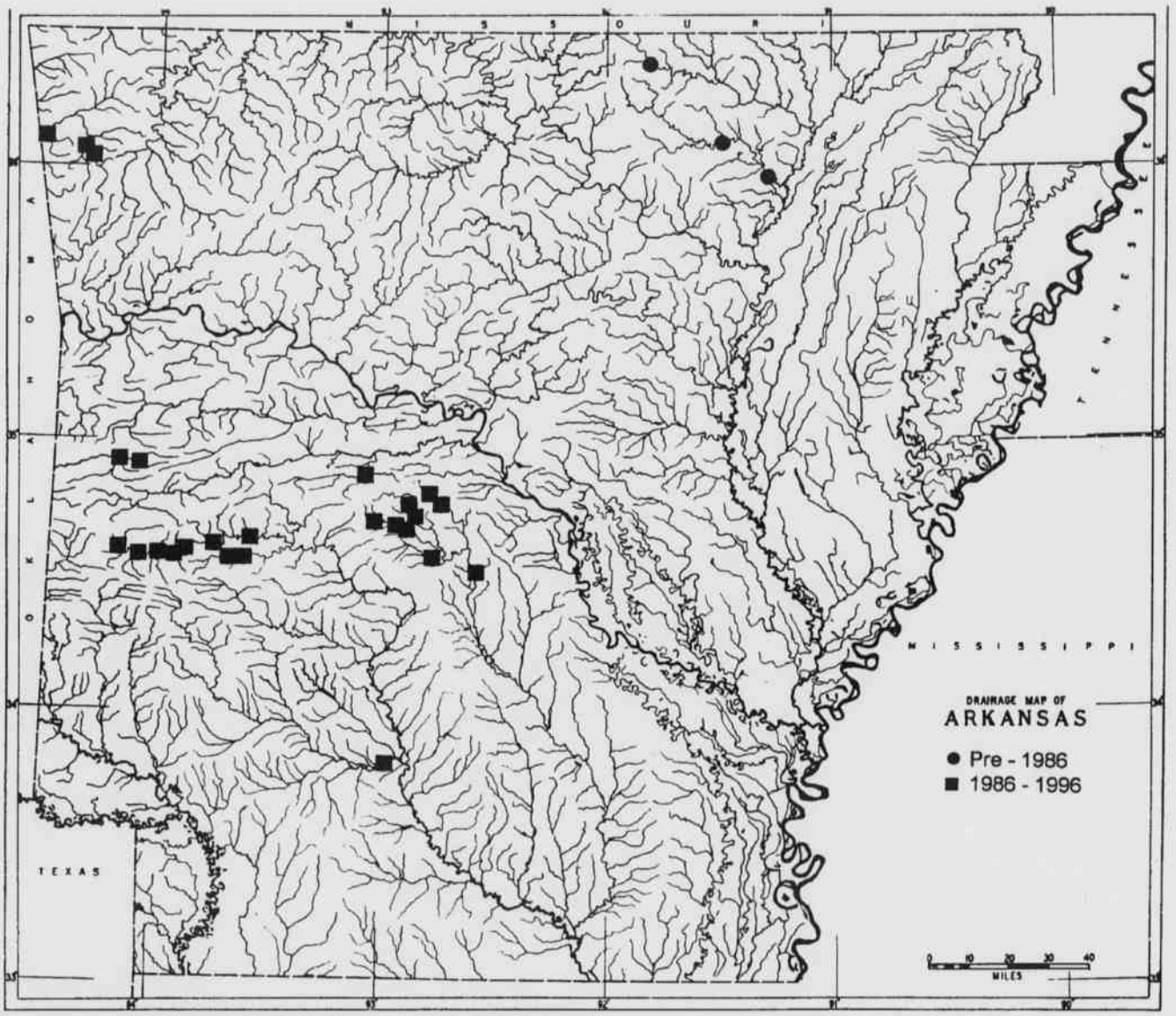

Fig. 15. Distribution of *Toxolasma lividus*

rized the distribution of the pyramid pigtoe within the St. Francis River drainage where a total of 78 specimens, which represented 0.6% of total riverine unionaceans examined, was found at 12 sites .

Lampsilis ornata (Conrad) - southern pocketbook. Distribution: Harris and Gordon, (1987). STATUS: State - Uncertain.

Harris and Gordon (1987) listed this species as *Lampsilis excavata* (Lea, 1857). No additional data have been acquired since Harris and Gordon (1987), and the taxononmic status of specimens referred to as this species is uncertain.

Conclusions

Twenty-two of the 75 unionacean bivalve species (29.3%) considered native to Arkansas deserve conservation status listing. Seven species are listed as federally endangered, and these include *Arkansia wheeleri*, *Epioblasma florentina curtisi*, *E. turgidula*, *Lampsilis abrupta*, *L. streckeri*, *Potamilus capax*, and *Quadrula fragosa*. Additionally, *Lampsilis powelli* is listed as federally threatened

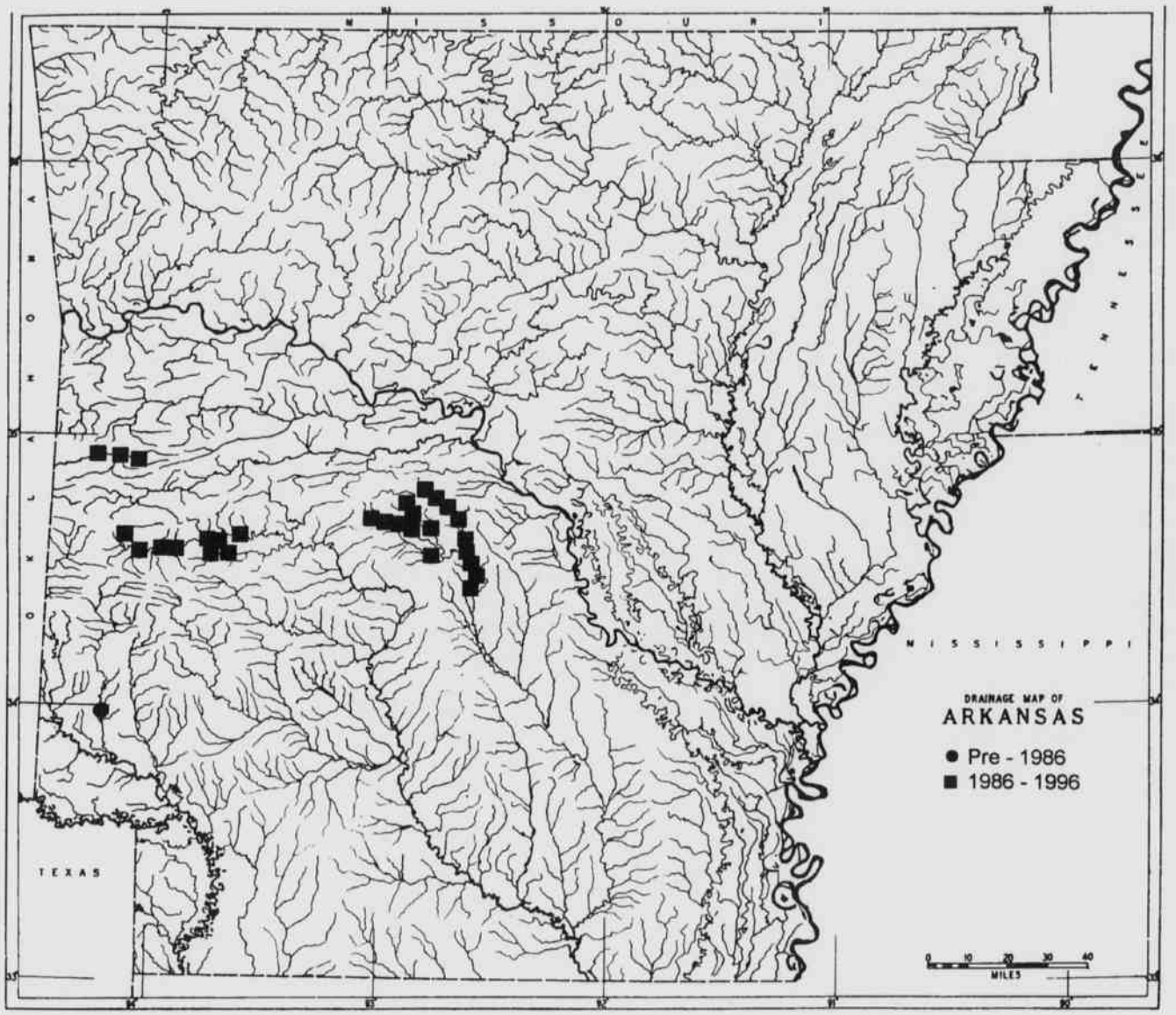

Fig. 16. Distribution of *Villosa arkansasensis*.

Ten unionacean species are herein listed endangered within Arkansas, and two of these, *Epioblasma florentina curtisi* and *E. turgidula*, may be extirpated from the state. Seven additional unionaceans are viewed as threatened and six others appear to warrant special concern. Four species listed as endangered, threatened or special concern in Arkansas are considered currently stable in North America (Williams et al., 1993). Two of these species, *Quadrula apiculata*, and *Potamilus alatus*, are on the periphery of their ranges in Arkansas. The third, *Anodonta suborbiculata*, inhabits waters that are difficult to survey so that our current understanding of its relative abundance and distribution may be underestimated.

The remaining 20 unionaceans afforded conservation status listing within Arkansas are considered worthy of concern rangewide also (Williams et al., 1993). Ten Arkansas unionaceans received conservation listing due to restricted distribution. These species include *Alasmidonta viridis*, *Arkansia wheeleri*, *Cumberlandia monodonta*, *Epioblasma florentina curtisi*, *E. triquetra*, *E. turgidula*, *Lampsilis rafinesqueana*, *L. streckeri*, *Quadrula fragosa*, and *Simpsonaias ambigua*. All ten species have restricted distributions with extant populations limited to one or two river drainages. In addition to the potentially extirpated species previously discussed,

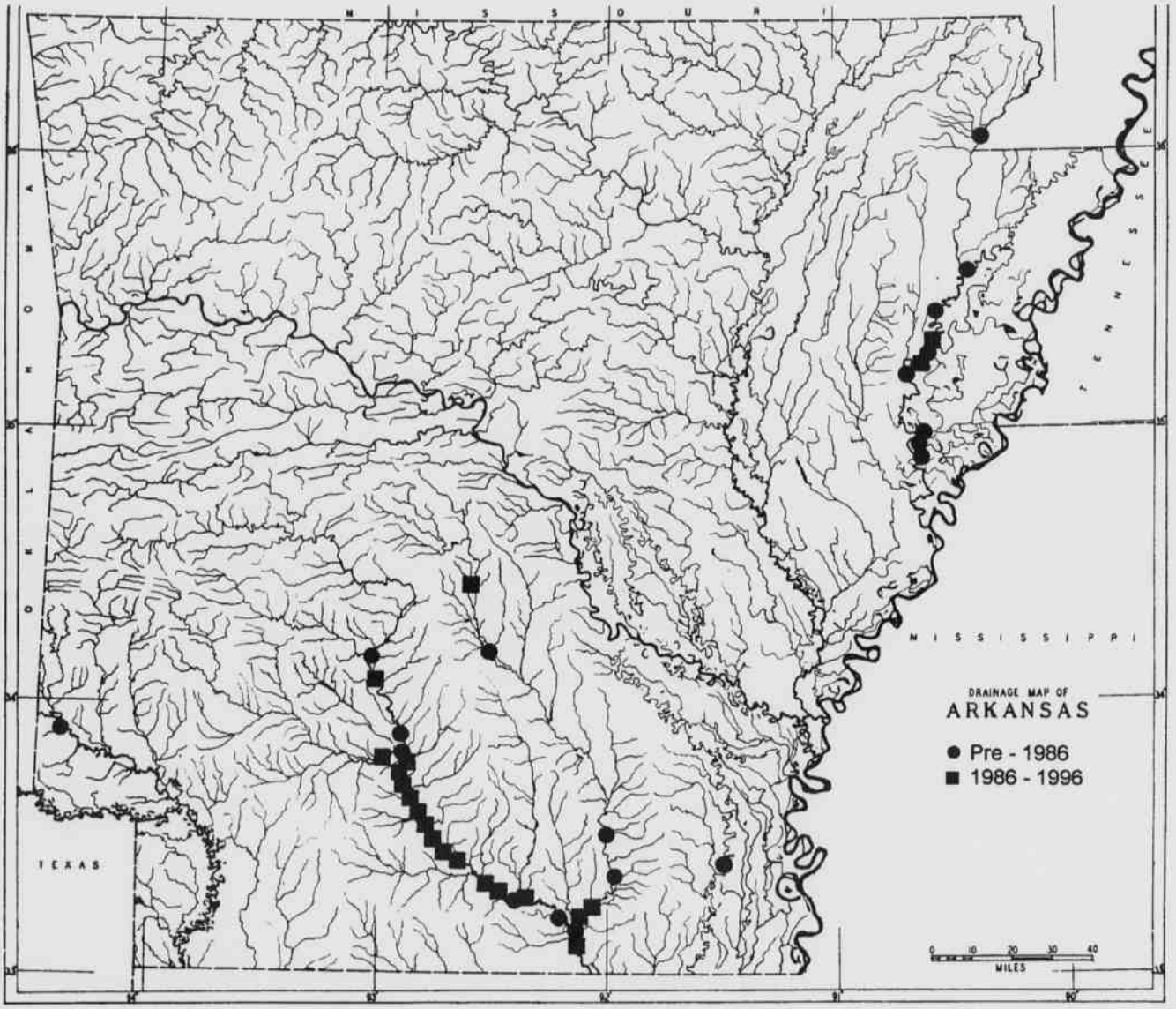

Fig. 17. Distribution of *Pleurobema pyramidatum*.

Alasmidonta viridis, *Arkansia wheeleri*, *Cumberlandia monodonta*, and *Simpsonaias ambigua* are known from three or fewer localities.

The remaining nine species are widely distributed but typically occur in very low numbers at each site. These species include *Lampsilis abrupta*, *L. powelli*, *Potamilus capax*, *Cyprogenia aberti*, *Leptodea leptodon*, *Obovaria jacksoniana*, *Quadrula c. cylindrica*, *Toxolasma lividus*, and *Villosa arkansasensis*. If preferred habitats were not subject to alteration, several of these species could be listed as currently stable.

Williams et al. (1993) summarized the potential threats to endangered unionaceans under broad categories which included habitat destruction, introduction of nonindigenous species, and pollution. Habitat destruction resulting from impoundments (including secondary impacts associated with construction) (Brown and Brown, 1989; Harris, 1989c); construction of highways (Harris et al., 1992), water intake facilities (Harris, 1991c, 1991d), pipelines (Harris, 1990a, 1990c, 1991b, 1992c) and boat ramps (Harris, 1986, 1989d); and dredging associated with commercial mining (Harris, 1987, 1994c, 1995, 1997c), drainage projects (Jenkinson, 1989; Harris 1997a), and navigation (Christian, 1995; Posey, 1997) have undoubtedly reduced the quantity and/or quali-

ty of available habitat in riverine systems. Pollution, primarily in the forrn of sedimentation, resulting from agricultural practices, silvicultural activities, and road building has negatively impacted localized unionacean communities (Brown and Brown, 1989; Harris, 1992a, 1996).

The nonindigenous zebra mussel (*Dreissena polymorpha*) occurs in both the Arkansas and White rivers. Davidson (1997) discussed adverse impacts due to zebra mussels to Arkansas River system unionaceans. The potential exists for extirpation of native species within entire river drainages (Riccardi et al., 1995).

Uncertainties regarding unionid bivalve taxonomy and systematics continue to plague efforts to understand the relative abundance and conservation priority status for many species. Taxonomic uncertainty regarding the *Lampsilis abrupta* complex (Harris and Gordon, 1987) has not been been resolved. The identification of specimens currently referred to as *Lampsilis ornata* are uncertain, as are identifications of taxa within the genus *Pleurobema.* In addition, morphological variation of shell characters in the taxa currently recognized as *Cyprogenia aberti, Elliptio dilatata,* and *Ptychobranchus occidentalis* suggests that some level of differentiation may have occurred and taxonomic recognition may be warranted. Specifically, specimens from the White and St. Francis river drainages are distinct and recognizeable from their counterparts found in the Ouachita, Arkansas and Red river drainages. Obviously, more rigorous analysis using comparisons of internal anatomy and biochemical systematic techniques should be undertaken.

Finally, the lack of unionacean surveys for many stream systems hampers true understanding of conservation status listings. Relatively large Arkansas River tributaries such as Illinois Bayou, Fourche La Fave River, Petit Jean River, Point Remove Creek, Cadron Creek, Maumelle River and Little Maumelle River have not been surveyed to determine unionacean bivalve species composition and distribution. Within the Ouachita River system, little is known regarding the unionaceans of Bayou Bartholomew, Terre Noire Creek or the Antoine River. Within the White River System, systematic unionacean surveys have not been conducted for the Kings River, War Eagle Creek or Eleven Point River systems. Many Red River system tributaries such as Cossatot River, Saline River, Bodcau Bayou, and Dorcheat Bayou remain relatively unknown regarding their unionacean faunas. Obviously, much work remains to be completed before the distribution and relative abundance of Arkansas unionaceans can be truly assessed.

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Electron Shock Waves: Effect of Current on Electron Temperature and Number Density

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Abstract

In our attempt to find analytical solutions for breakdown waves, we employ a set of three-component fluid equations. In addition to reporting the method of integration of electron fluid dynamical equations through the dynamical transition region (sheath region), the wave profile for ionization rate, electron number density and electron temperature inside the sheath will be discussed. Also, the effect of the current on electron temperature, electron number density and ionization rate will be reported.

Introduction

For theoretical investigation of breakdown waves a one-dimensional, steady-state, three-component fluid model with a shock front driven by electron gas partial pressure was first presented by Paxton and Fowler (1962). In their model they considered both photoionization and electron impact ionization as important ionization processes. In the fluid model the basic set of equations consists of equations of conservation of mass, momentum, and energy, coupled with Poisson's equation. The system of equations is based on the interactions of three fluids: neutral particles, ions, and electrons. The lack of an experimentally observed Doppler shift in the spectrum of the emitted radiation indicates that in the laboratory the ions and neutral particles have no substantial motion. The fluid phenomenon, therefore, must be due to electron fluid motion alone. Paxton's approximate solutions had a limited success.

Paxton's model was later expanded and modified by Shelton and Fowler (1968). To describe the breakdown waves, Shelton and Fowler (1968) used the terms proforce and antiforce waves, depending on whether the applied electric field force on electrons was with or against the direction of wave propagation. For example, return strokes of lightning flashes are referred to as antiforce waves. Shelton's modified version used frame invariance to find analytic forms for elastic and inelastic collision terms, and the ionization was considered to be due to electron impact only. Shelton's approximation methods in solving the electron fluid equations with "certain limiting conditions governing the existence of such steady-profile waves" had relatively good agreement with experimental results in the allowed limited range of wave speeds.

Following Fowler's (1976) classification, the breakdown waves propagating into a nonionized medium will be referred to as Class I waves, those moving into a preionized medium will be called Class II waves, and the waves for which a large electric current exists behind the shock front will be referred to as Class III waves. If a contained volume of plasma is subjected to an electric field, a Debye sheath layer will form. Excess charges of one polarity create a space charge field in the layer which cancels out the applied field. The interior region of the plasma, therefore, is essentially field free and neutral. The thin Debye region in which the field falls to a negligible value and the electrons come to rest relative to the heavy particles, will be referred to as the sheath region.

Theory and Model

In the one-dimensional model of electrical discharges, assuming that the electric field is in the direction of the negative x-axis (proforce waves), the electric field force on electrons will be in the direction of the positive x-axis. In the neighborhood of the pulsed electrode, the electric field is very large and intense ionization takes place. The field accelerates the free electrons until they attain enough energy for collisional ionization of the gas. The intense electric field, the highest intensity of which is considered to be at the interface between the neutral gas and the ionized gas, causes the continuation of this process and forward motion of the interface into the neutral gas. For ionizing waves (also referred to as potential waves), the interface is a shock front.

The shock front in breakdown waves is followed by a dynamical transition region. The transition region, which is somewhat thicker than a Debye length will be referred to as the sheath region. In the sheath region electrons come to rest relative to neutrals, and the net electric field falls to zero at the trailing edge of the sheath. The large difference in electron and ion mobility results in the establishment of space charge and therefore, of a space charge field inside the sheath. The net electric field is the sum of the applied field and the space charge field. The sheath region is followed by

a relatively thicken quasi-neutral region in which the electron gas heated in the sheath region cools off by further ionizing the neutral particles. In the wave frame, an observer traveling with the wave will see a cold gas enter the sheath region from the front while a partially ionized gas leaves the rear side of the sheath. For breakdown waves to advance without significant damping, during ionization inside the sheath the change of electron fluid momentum must be small compared to the force due to the electron gas pressure gradient. The electron gas partial pressure, therefore, is considered to provide the driving force in the fluid dynamical analysis of the ionizing waves.

In our attempt to find analytical solutions, we will employ a set of three-component fluid equations which were completed by Fowler et al. (1984). They have reduced their original system of twelve electron fluid equations (continuity, momentum, and energy conservation) in tensor notations to a single system of nonlinear differential equations. Their system of electron-fluid equations plus Poisson's equation for breakdown of ionless media, respectively, are

$$\frac{d(nv)}{dx} = \beta n, \tag{1}$$

$$\frac{d}{dx}\left\{ nmv(v - V) + nkT_e \right\} = -enE - Kmn\ (v - V), \tag{2}$$

$$\frac{d}{dx}\left\{ nmv(v - V)^2 + nkT_e\,(5v - 2V) + 2e\phi nv + \epsilon_0 VE^2 - \frac{5nk^2\,T_e}{mk}\frac{dT_e}{dx} \right\}$$

$$= -3\left(\frac{m}{M}\right) nkKT_e - mnK\left(\frac{m}{M}\right)(v - V)^2, \tag{3}$$

$$\frac{dE}{dx} = \frac{en}{\epsilon_0}\left(\frac{v}{V} - 1\right). \tag{4}$$

The symbols m, e, n, and T_e represent electron mass, charge, number density, and temperature inside the sheath, and K, β, ϕ, V, M, E_0, x are elastic collision frequency, ionization frequency, ionization potential, wave velocity, neutral particle mass, electric field at the wave front, and position inside the sheath, respectively.

Analysis

The analysis will partially involve the use of methods similar to those employed by Fowler et al. (1984). Introducing dimensionless variables

$$\theta = \frac{kT_e}{2e\phi}, \quad \eta = \frac{E}{E_0}, \quad \xi = \frac{eE_0}{mV^2}x, \quad \psi = \frac{v}{V}, \quad \omega = \frac{2m}{M}, \quad \kappa = \frac{mVK}{eE_0},$$

$$\mu = \frac{\beta}{K}, \quad \alpha = \frac{2e\phi}{mV^2}, \quad \nu = \frac{2e\phi}{\epsilon_0 E_0^2}\,n$$

into the system of electron-fluid equations, one can achieve nondimensionalization of the equation set.

$$\frac{d(\nu\psi)}{d\xi} = \kappa\mu\nu,$$

$$\frac{d}{d\xi}\left\{\nu\psi(\psi - 1) + \alpha\nu\theta\right\} = -\nu\eta - \kappa\nu(\psi - 1),$$

$$\frac{d}{d\xi}\left\{\nu\psi(\psi - 1)^2 + \alpha\nu\theta(5\psi - 2) + \alpha\nu\psi + \alpha\eta^2 - \frac{5\alpha^2\nu\theta}{\kappa}\frac{d\theta}{d\xi}\right\} = -\omega\kappa\nu\left\{3\alpha\theta + (\psi - 1)^2\right\}.$$

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1).$$

In the above equations, ν, ψ, θ, μ, κ, η, and ξ are the dimensionless electron concentration, electron velocity, electron temperature, ionization rate, elastic collision frequency, electric field, and position inside the sheath, respectively.

For proforce current bearing waves (Class 111 waves) to integrate the set of electron-fluid-dynamical equations through the sheath region, we will use Hemmati and Young's (1995) modified Poisson's equation and their equation for electron temperature at the shock front. The two equations have proven to be successful in solving the problem, and they, respectively, are

$$\frac{d\eta}{d\xi} = \frac{\nu}{\alpha}(\psi - 1) + \kappa\iota, \tag{9}$$

$$\theta_1 = \frac{\psi_1(1 - \psi_1)}{\alpha} + \frac{\kappa}{\nu_1}\iota, \tag{10}$$

where $\iota = \frac{I_1}{\epsilon_0 E_0 K_1}$, with I_1 as the current behind the shock front.

In a review of the present understanding of lightning, Uman (1993) identifies four different types of lightning between cloud and Earth. A typical cloud-to-ground lightning flash starts with a "step leader" which then propagates down from the top in quantized steps of about 50 meters in length. Leader steps have a duration of 1 μs and pause time of approximately 20 to 50 μs. The total time elapsed until the step leader touches the ground is approximately tens of milliseconds, and its average speed is about 2×10^5 m/s. Following the last step, a very bright wave containing a large amount of charge moves very quickly from the ground to the cloud. This is referred to as the return stroke. The duration of time elapsed until the return stroke traverses the length of the previously charged leader channel is on the order of 100 μs, and it has a speed roughly one-third the speed of light. After a period of tens of milliseconds, if additional charge is available at the bottom of the cloud, a wave propagates smoothly from the cloud to the ground along the first-stroke channel. This wave is referred to as the dart

leader, and it will be followed by a new return stroke. From observations on twenty-one dart leaders, Orville and Idone 1982) report total distances in the range of 3.5 – 17.2 km, speeds in the range of 2.9 to 23 x 10^6 m/s, and average dart length of 34 m. The dart leader lowers a total charge on the order of 1 C during a total time on the order of 1 ms.

Allowing lightning discharge to pass through fiberglass screen, Uman (1964) has been able to determine the diameter of the lightning stroke. Considering the diameter of the inner core as the diameter of the lightning, his measurements resulted in values in the range of 2 to 3.5 cm for the diameter of the lightening stroke. For a dart leader carrying electron number density of n ~ 10^{13} e/cm^3 (Fowler, 1964) with a channel radius of r ~ 2 cm, and propagation speed of v ~ 10^6 m/s, one can calculate the approximate value of conduction current from the equation I = nevA to be I ~ 2000 A. Similar calculations of the current in a stepped leader will result in an average value of 500 A, and peak current value of 30 KA for a return stroke.

The value of the dimensionless current, ι, depends on the choice of values of electric field at the wave front, E_0, and elastic collision frequency , K, where both are scaled with electron pressure. Using the appropriate values of K for nitrogen and with current magnitudes calculated in the last paragraph, the value of ι will be on the order of 0.005–0.1.

The first objective of this paper is the integration of the electron-fluid dynamical equations for proforce Class III waves. To achieve integration of the set of equations through the sheath region, one has to place the singularity inherent in the equation system in the denominator of the momentum integral (Fowler et al., 1984).

$$\frac{d\psi}{d\xi} = \frac{\kappa\psi(1+\mu)(1-\psi) - \alpha\theta\kappa\mu - \alpha\psi\theta' - \eta\psi}{\psi^2 - \alpha\theta} \qquad (11)$$

A zero denominator in the momentum integral represented an infinite value for the electron velocity derivative with respect to the position inside the sheath. This condition requires the existence of a shock inside the sheath region, which is not allowed. The numerator in the momentum integral, therefore, has to become zero at the same time that the denominator becomes zero. For a given wave speed in the process of integration of the equations through the sheath region, comparing the numerator and denominator values will allow one to choose the required initial parameters (v_1, ψ_1, and κ) by trial and error. A successful solution has to allow passage through the singularity and satisfy the physically acceptable conditions at the trailing edge of the sheath. The expected conditions at the end of the sheath are, a) the electrons have to come to rest relative to neutral particles ($\psi \rightarrow 1$), and b) the net electric field has to reduce to a negligible value ($\eta \rightarrow 0$). Our solutions satisfy the expected boundary conditions at the trailing edge of the wave within the accuracy of the integration step.

All the current values which allow for the integration of the set of electron-fluid equations through the sheath region have been investigated. This has resulted in a theoretically calculated current range using electron fluid approach. The prepared successful current range (ι = 0.001 ~ 0.5) compares well with the range of current values calculated in this paper and current ranges measured by a number of researchers. This agreement on current range is another confirmation on the validity of the electron-fluid model for electrical discharge of gases. The following are several articles with different methods of current measurements or calculations.

In two succeeding articles Uman and McLain were able to derive expressions relating the current in lightning to the radiation field (electric field intensity or magnetic flux density). In their first article (Uman and McLain, 1970a), their calculated value of the peak current for the typical stepped leader waveform described by Pierce was between about 800 A and 5 KA. The derived expressions in their second article (Uman and McLain, 1970b) allowed them to calculate the current in a lightning return stroke from a measurement of the radiation field. They reported a typical stepped leader peak field of about 1/20 of the peak field of a typical return stroke at 100 Km. In analyzing the data, they assumed that the ratio of the peak fields is proportional to the ratio of the maximum rates of change of current. In a separate article, "Comparing Lightning and Long Laboratory Spark for Stepped Leader," Uman (1971) reports an average current of 100 A and a peak current of 1000 A. Treating the current behind the wave front as a switch-on transient in a transmission line, Little (1978) was able to model and calculate the variation of current in a return stroke with altitude. His calculated value of the average peak current in the stroke is roughly 88 KA.

Results

The integration of the system of electron fluid dynamical equations provides variations on electron temperature, electron number density and ionization rate within the sheath region. In our investigation, the current values selected were 0.001, 0.01, 0.1, 0.25, and 0.5. We were able to integrate the system of equations through the sheath region even for current value as high as 0.5. For ι = 0.5, however, the passage through the singularity required keeping the numerator and denominator in the momentum integral constant up to 25 integration steps. This results in a kink in the graphs when variables such as θ, v, and μ are plotted. Our graphs, therefore, include current values up to 0.25.

We have integrated the system of electron fluid dynam-

ical equations for a fast moving wave ($\alpha = 0.01$, $V = 3 \times 10^7$ m/s). Figure 1 is a plot of electric field, η, as a function of electron velocity, ψ, inside the sheath. For all current values, the results meet the expected boundary conditions at the end of the sheath ($\eta \to 0$, $\psi \to 1$). Figure 2 is a plot of electron temperature, θ, as a function of position, ξ, inside the sheath. The results conform with the expected variations of the electron temperature within the sheath. For all current values, the electron gas temperature decreases near the end of the sheath.

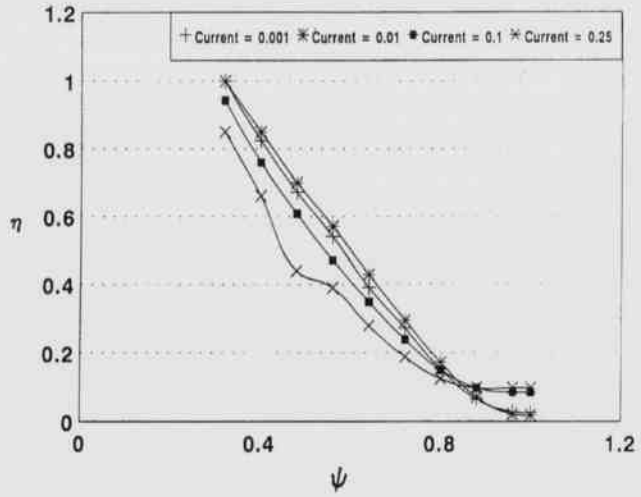

Fig. 1. Electric field, η, as a function of electron velocity, ψ, inside the sheath.

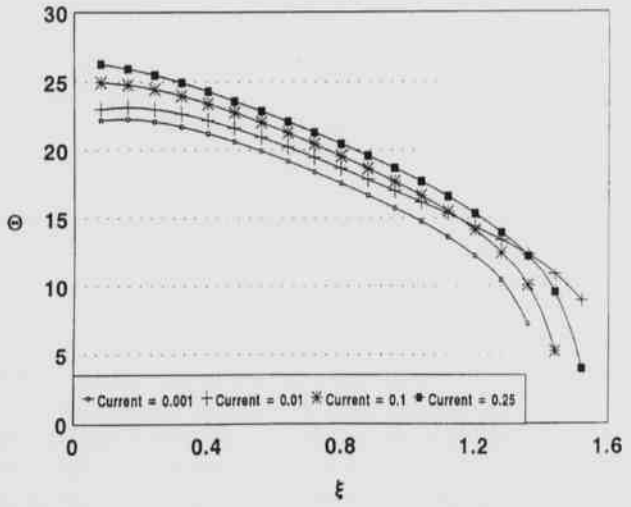

Fig. 2. Electron temperature, θ, as a function of positions ξ, inside the sheath.

Figure 3 is a graph of electron number density, ν, as a function of position inside the sheath. For current value of 0.25, the passage through the singularity requires a higher level of approximation and therefore, provides a kink in the graph of electron number density as a function of position, ξ.

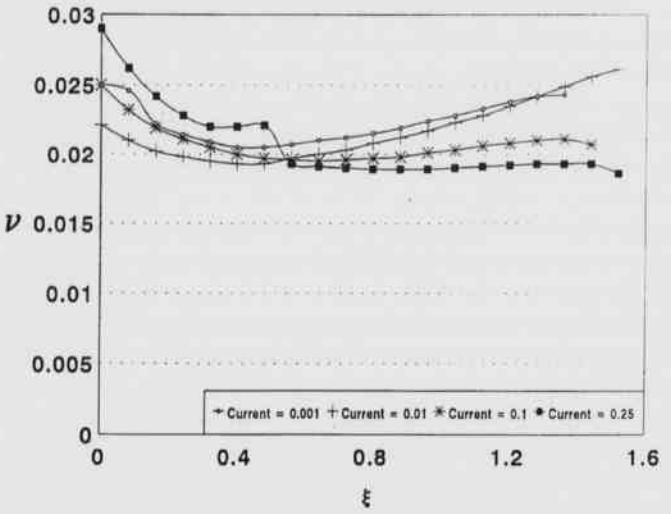

Fig. 3. Electron number density, υ, as a function of position, ξ, inside the sheath.

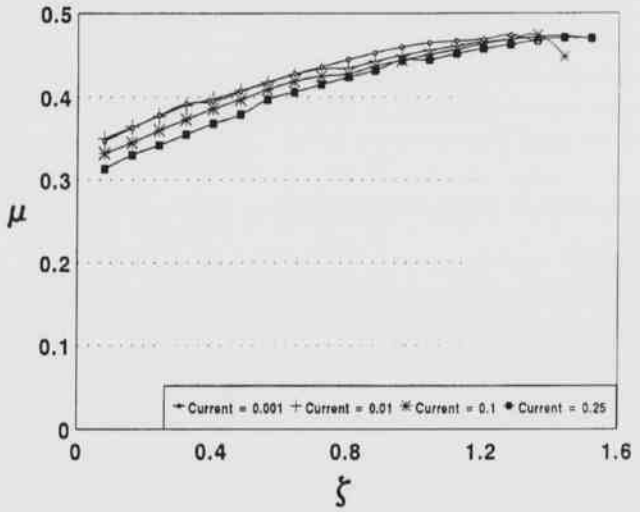

Fig. 4. Ionization rate, μ, as a function of position, ξ, inside the sheath.

Figure 4 represents the variation of ionization rate, μ, as a function of position inside the sheath. The earlier assumption, that the ionization rate throughout the region where electric field is present was held constant, has been replaced by using a double integral to calculate it [Fowler et al. (1984)]. As Fig. 4 indicates, the ionization rate derived, based on the directed as well as random motion of electrons, changes within the sheath region.

Conclusions

As Fig. 4 indicates, for all current values the ionization ate increases near the trailing edge of the sheath. This is ue to high electron temperatures which make further ion- zation possible. The results indicate that the sheath thick- ess is effected by the changes in the value of the current ehind the shock front. As the current increases the sheath hickness also increases slightly. Solutions for smaller wave ropagation speeds are possible; however, the integration of he set of electron fluid equations become more difficult as he wave speed decreases.

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Age, Growth and Condition of Largemouth Bass, *Micropterus salmoides*, of Lake Ashbaugh, Arkansas

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Abstract

The population size structure, length at age and condition of 140 largemouth bass, *Micropterus salmoides*, were studied for Lake Ashbaugh, Arkansas. Scales and otoliths were used for age and length at age determination of individual bass. Length at age was determined by back-calculation and relative weight was used to measure condition. The Lake Ashbaugh population is dominated by young, slow growing bass in poor condition. Ninety-one percent of the largemouth bass in Lake Ashbaugh were less than four years of age, with age 3+ bass serving as the dominant year class. Proportional and relative stock density values were 25 and 3 %, respectively, significantly less than those of other surveyed Arkansas reservoirs. The mean relative weight for this population was 84, significantly less than that projected for healthy populations. Mean back-calculated lengths for largemouth bass ages I through age III were 141 mm, 190 mm, and 257 mm, respectively. Mean lengths at each age were significantly less than those obtained from a 1987 study of Lake Ashbaugh bass and for bass in other Arkansas reservoirs. Several factors may have contributed to the steady decline in the bass population of Lake Ashbaugh. Winterkills occurred in 1989-1991, which seemed to affect mostly mature largemouth bass. A 380 mm length limit imposed in 1987 may have resulted in a stockpiling of bass less than 380 mm, increasing the competition for available prey for those size classes. These hypotheses are supported by consistent yearly declines over the past five years in the available prey/predator ratios and relative weights, particularly for the size classes between 226 mm-350 mm.

Introduction

The largemouth bass, *Micropterus salmoides* (Lacepede), is the best known and most widespread of the six species of Micropterid black basses. The native range of the largemouth bass (LMB) occurs in southeastern Canada, northeastern Mexico, and the eastern half of the United States, except for the region east of the Appalachian mountains (Robbins and MacCrimmon, 1974). Numerous reservoirs have been constructed throughout the United States, including Arkansas, and, due to its adaptability and growth characteristics, the range of the largemouth bass has been dramatically extended.

Lake Ashbaugh is a 243 hectare lake constructed in 1981 and located in Greene County (long. 90°45' and lat. 36°15') in northeast Arkansas. It has a maximum depth of 3.8 with a mean depth of 2.0. The major bass habitat types of Lake Ashbaugh include stumps, cypress trees, floating logs and emergent weeds, which are ideal bass habitats. Initial growth rates were quite good, as is typical for new reservoirs. However, there has been a progressive deterioration in the LMB fishery in Lake Ashbaugh over the past several years despite changes in length limits to improve recruitment and growth (Barkley and Henry, 1992a).

The Arkansas Game and Fish Commission annually estimates population structure and condition of fishes on managed reservoirs. The objectives of the present study were to provide a more in-depth analysis on population size structure, length at age, and condition of the LMB of Lake Ashbaugh, to investigate parameters contributing to this declining fishery, and to compare these results with other reservoirs within Arkansas and adjoining states.

Materials and Methods

Largemouth bass (n = 140) were collected by electrofishing from Lake Ashbaugh in May of 1992 with the assistance of Arkansas Game and Fish Commission. Length and mass of each bass were measured to the nearest mm and gm. Largemouth bass were separated into distinct 25 mm length groups ranging from 126 mm to 600 mm, and the frequency for each length class was determined. Proportional and relative stock densities were calculated for the sample. The stock population is defined as those LMB in the population which are greater than 200 mm in length. The proportional stock density (PSD) is an index which expresses the percentage of bass in the stock population which are 300 mm or greater in length. The relative stock density (RSD) is a variation of the PSD and is an index which expresses the number of bass in the stock population which are 380 mm or greater in length (Anderson and Gutreuter, 1983).

Scales and otoliths were removed from LMB collected. No differences were observed when using scales or otoliths for age determination, which is consistent with findings by Doerzbacher and Schramm (1982). Scales were mounted in acetate, projected onto a screen, and annuli identified to determine age. Bass were categorized as young of year (YOY), age 1+, age 2+, etc. Otoliths of young bass (< age 3+) were cleared in glycerin, mounted on a microscope slide, and projected onto a screen using a microprojector. Otoliths of older LMB were cross-sectioned to a thickness of 0.5 mm, polished and measured as discussed above.

The length of the bass at each growing season was determined by using the Fraser-Lee method for back-calculation (Fraser, 1916; Lee, 1920), with an α intercept of 20 (Carlander, 1982). To reduce the effects of Lee's phenomenon, mean back-calculated lengths were calculated for only the two most recent growing seasons for bass older than three years of age (Carlander, 1982).

Condition was measured using relative weight for each individual LMB (Wege and Anderson, 1978). Relative weight is defined as the actual weight of a fish divided by a standard weight for the same length for that species times 100 (Anderson and Gutreuter, 1983). Both Wege and Anderson (1978) and Henson (1991) constants were utilized, as traditionally the Wege and Anderson (1978) constants have been used in condition studies, while Henson (1991) constants were recently recommended by Murphy et al. (1991), as reducing size bias.

The following statistical applications were utilized to compare the 1992 data obtained with that of previous work performed on Lake Ashbaugh and other reservoirs in Arkansas (Beaver Lake, DeGray Lake, Lake Catherine, Lake Chicot, Lake Erling, Lake Norfork, and Lake Ouachita). Contingency tables were prepared with chi square analysis performed for the parameters of proportional stock density and relative stock density to compare values obtained for Lake Ashbaugh versus the Arkansas reservoirs listed above. This analysis provided a comparison of quality bass size structure for Lake Ashbaugh versus other Arkansas reservoirs, with Lake Ashbaugh's bass size structure frequencies serving as the standard (expected) for comparison with other reservoirs. A two sample *t*-test compared the mean back-calculated length at age for the present study versus a previous study in 1987, and versus other reservoirs in Arkansas. A two-tailed *t*-test determined the significance of differences between Wr of the present study as compared to optimal values recommended by Wege and Anderson (1978). Pearson-Product correlation coefficients were determined for relative weight versus back-calculated length at age for reservoirs in Arkansas, for relative weight versus the number of individuals per cohort and available prey to predator ratios obtained for Lake Ashbaugh.

Results and Discussion

Length Frequency.--Length frequency was determined for the largemouth bass of Lake Ashbaugh, with bass categorized in 25 mm size groups (Table 1). The most frequent size groups were 176-200 mm and 201-225 mm. A vast majority (97%) of the bass were below the 380 mm length limit established by the Arkansas Game and Fish Commission in April 1987, giving a RSD of three percent. The PSD for the Lake Ashbaugh 1992 bass population was 25%.

Table 1. Comparison of relative and proportional stock densities of LMB by way of Chi square analysis for Lake Ashbaugh for years 1986-1991 to the 1992 sample[1].

YEAR	RSD	PSD
1986	26***	36*
1987	31**	50***
1988	14**	56***
1989	16**	49***
1990	12**	39**
1991	5	14*
1992	3	25

[1]Armstrong et al., (18 = 986; 1987; 1988); Roberg and Henry (1989); Armstrong et al. (1990); and Barkley and Henry (1991).

* indicates significance difference at $P<0.05$.
** indicates significance difference at $P<0.01$.
*** indicates significance difference at $P<0.001$.

There has been a consistent decrease in the size structure of the LMB of Lake Ashbaugh over the past six years. The RSD value peaked in 1987 at 31, and the PSD value peaked in 1988 at 56 but both have rapidly and significantly declined thereafter (Table 2). These decreasing harvestable numbers are due in part to winterkills in 1989, 1990 and 1991 that affected thousands of adult LMB within the population. This factor, along with poor recruitment of young bass into the population, has contributed to the reduction in size structure of largemouth bass in Lake Ashbaugh (Barkley and Henry, 1991). A 300 mm length limit was in effect on Lake Ashbaugh from its impoundment in 1981 to April of 1987, when a 380 mm length limit was established. The largemouth bass population was in its boom period at the time of the length limit change; however, many adult bass were harvested soon after reaching the legal size limit (Armstrong et al., 1990). The purpose of establishing length limits is to protect bass stocks from

impending overharvest, increase catch rates of sub-legal sized bass, and to affect changes in the forage population through predator and prey relationships (Ming and McDannold, 1975). However, four years after the change, the 1992 RSD was approximately three percent. This may be in part the result of the 380 mm length limit not having served its purpose. Contradictory results have been obtained by game and fish agencies using minimum length limits to control stock composition (Timmons, 1985; Mitchell and Sellers, 1989), although slot limits have improved stock composition through the harvesting of smaller bass (Summers, 1988).

Table 2. A comparison of relative and proportional stock densities of LMB by way of Chi square analysis of Lake Ashbaugh with other reservoir populations in Arkansas.

Lake Name	Location (county)	Sample Year	Stock Densities	
			Relative	Proportional
Ashbaugh	Green	1992	3	25
Beaver[1]	Benton	1991	23***	57***
Catherine[1]	Hot Springs	1991	36***	87***
Charles[2]	Lawrence	1992	7	13**
Chicot1	Chicto	1991	23***	64***
DeGray[1]	Clark	1991	45***	73***
Erling[1]	Lafayette	1991	40***	90***
Hogue[3]	Poinsett	1992	21***	46***
Norfolk[1]	Baxter	1991	33***	73***
Ouachita[1]	Garland	1991	47***	75***
Poinsett[4]	Poinsett	1992	18***	68***

[1]Fishery Management Information Systems (1991).
[2]Barkley and Henry (1992b)
[3]Barkley and Henry (1992c)
[4]Barkley and Henry (1992d)

* indicates significance difference at $P<0.05$.
** indicates significance difference at $P<0.01$.
*** indicates significance difference at $P<0.001$.

A comparison of the size structure of Lake Ashbaugh bass versus those of other Arkansas reservoirs sampled by the Arkansas Game and Fish Commission demonstrated that the 1992 RSD value from Lake Ashbaugh was significantly lower than for all of the lakes compared (Table 3). The PSD of Lake Ashbaugh was also determined to be significantly lower than for all other reservoirs except for Lake Charles, which had a significantly lower PSD value than did Lake Ashbaugh.

Table 3. Comparison of 1987 and 1992 age structure and length at capture of largemouth bass of Lake Ashbaugh (Standard deviations in parenthesis) {*t*-test}.

Age	1987[1] Length (mm) at Capture	1987[1] Number	1992 Length (mm) at Capture	1992 Number
1+	219 (43)***	27	173 (19)	42
2+	305 (33)***	23	219 (13)	26
3+	388 (29)***	10	290 (29)	60
4+	438 (38)***	13	375 (46)	8
5+	464 (28)	13	450 (N/A)	1
6+	530 (N/A)	3	500 (N/A)	1
7+	562 (N/A)	1	510 (N/A)	1
8+	N/D (N/A)	0	N/D (N/A)	0
9+	N/D (N/A)	0	N/D (N/A)	1

[1]Armstrong et al. (1987).

*** indicates significance at $P<0.001$.

Age Structure.--Eight age groups were identified for the 140 largemouth bass sampled. No largemouth bass older than nine years of age were identified, and no young of the year bass were represented in this study due to the nature of the sampling methods.

Few LMB (8.6%) were age four years old and older, with the age 3+ bass (43%) representing the greatest proportion of bass identified. All age groups greater than age 4+ LMB were represented by at most a single individual; therefore, all statistical comparisons for length at age and relative weight will not include bass older than 4+ (Table 4). The winterkills discussed previously explains in part the dominance of age classes from the years of 1990 through 1992 and the poor representation of earlier age classes. These events have drastically affected the population dynamics by decreasing the number of mature LMB.

The 1992 age structure of Lake Ashbaugh bass was compared to a 1987 study conducted by the Arkansas Game and Fish Commission. The age structure of the 1987 population was significantly different from the present sample population {$\chi^2 = 299.851$, $df = 6$; $P < 0.001$} (Table 4). In the 1987 sample, all age groups were well represented and recruitment was present for all age groups.

Age structure was also compared by way of chi square analysis with other Arkansas reservoirs studied in 1991 (Table 5). Lake Ashbaugh bass possessed a significantly different age structure than all other reservoir populations ($P<$ 0.001).

Length at Age.--Mean length at age was determined for

Table 4. Comparison of age structure of Lake Ashbaugh LMB with other reservoir populations in Arkansas[1].

Lake Name	Age Groups														
	1+		2+		3+		4+		5+		6+		7+		
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	Total
Ashbaugh	42	30.2	26	18.6	60	42.9	8	5.71	1	0.71	1	0.71	1	0.71	140
Beaver	56	41.2	42	30.9	20	14.7	11	8.1	4	2.9	1	0.74	1	0.74	136
Catherine	79	27.7	78	27.4	60	21.1	28	9.8	23	8.1	12	4.2	4	1.4	285
Chicot	159	41.4	153	39.5	43	11.2	17	4.3	9	2.3	3	.78	N/D		384
DeGray	235	32.5	212	29.3	123	17.0	88	12.2	50	7.0	15	2.1	1	0.14	724
Erling	128	32.9	128	32.9	84	21.6	29	7.5	14	3.6	4	1.0	2	0.51	389
Norfork	84	39.8	65	30.8	27	12.8	18	8.5	8	3.8	5	2.4	2	0.95	211
Ouachita	221	29.2	218	28.8	143	18.9	88	11.6	59	7.8	20	2.6	6	0.79	758

[1]Fishery Management Information Systems (1991).

Table 5. Comparison of 1987 and 1992 mean back-calculated length values for each age class of LMB for Lake Ashbaugh (*t*-test).

	1987[1]			1992		
Age Class	N	Back-calculated Length (mm)	Standard Deviation	N	Back-calculated Length (mm)	Standard Deviation
I	90	162***	50	140	141	20
II	63	248***	49	98	190	16
III	40	303***	52	72	257	26
IV	30	385***	51	12	331	6
V	17	444	41	4	425	N/A
VI	4	509	46	3	447	N/A
VII	1	562	N/A	2	496	N/A
VIII	0	N/D	N/D	1	N/D	N/D
IX	0	N/D	N/D	1	564	N/A

[1]Armstrong et al. (1987).

*** indicates significance at $P<0.001$.

each age group of LMB (Table 4). Largemouth bass in Lake Ashbaugh reach 300 mm by their third or fourth summer, and a legal size of 380 mm by the fourth or fifth summer (Table 4). The length at capture was demonstrated to be significantly higher for each age class from the 1987 survey of Lake Ashbaugh bass {*t*-test, $P< 0.001$} (Table 4). These same significances were observed when back-calculated lengths were compared for age groups I - IV of the 1987 and 1992 populations {*t*-test, $P< 0.001$} (Table 6).

The back-calculated lengths for largemouth bass, ages I to IV, of Lake Ashbaugh were significantly lower than for bass of other reservoirs studied with the exception of age I bass of Lake Ouachita {*t*-test, $P< 0.001$} (Table 7).

Length and Weight Relationships.--Relative weights were calculated for individuals, age groups, and total population. The largemouth bass of the 1992 sample population were in poor condition as indicated by low relative weights (Figure 1). Mean relative weights for this sample population were significantly lower than the optimum values of 100 ($t=$ 18.93; $P< 0.001$), as set forth by Anderson and Gutreuter (1983). Relative weight values were greatest for immature bass (age 1+). Conversely, age 3+ bass were the most frequent age group and possessed the lowest relative weight, with 43.3% having relative weight values falling between 62-79. However, there was no significant correlation identified for cohort size versus relative weight ($r= -0.32$).

Murphy et al. (1991), stated that the Wege and Anderson (1978) formula artificially inflates the relative weight of larger LMB at the expense of smaller LMB. This phenomenon was observed in the present study (Figure 1). Although Henson' s formula is the more accurate of the two, Wege and Anderson's formula has been so widely utilized that we used it for comparison purposes.

Historically, the condition of largemouth bass of Lake Ashbaugh was excellent and relative weights often exceeded the optimum 100 standard for all bass length groups (Roberg and Henry, 1989). However, condition has consistently decreased since the 1989 growing season (Figure 2). Relative weights obtained for LMB sized 200-400

Table 6. Comparison of back-calculated lengths at age in mm of largemouth bass of Lake Ashbaugh with other reservoirs in Arkansas (Standard deviations in parentheses)[1].

Lake Name	Age Groups						
	I	II	III	IV	V	VI	VII
Ashbaugh	141 (20)	190 (16)	257 (26)	331 (6)	425 (N/A)	447 (N/A)	496 (N/A)
Beaver	156 (4)***	274 (5)***	340 (7)***	368 (9)***	385 (17)	367 (N/A)	380 (N/A)
Catherine	162 (3)***	273 (4)***	348 (4)***	411 (6)***	449 (4)	473 (5)	504 (12)
Chicot	162 (2)***	295 (3)***	390 (6)***	444 (5)***	474 (5)	505 (14)	0 (ND)
DeGray	147 (2)***	265 (3)***	355 (3)***	419 (3)***	468 (4)	500 (8)	533 (N/A)
Erling	155 (3)***	283 (4)***	369 (3)***	427 (4)***	461 (5)	486 (6)	505 (10)
Norfork	165 (3)***	294 (6)***	370 (4)***	413 (4)***	439 (7)	481 (10)	522 (5)
Ouachita	133 (2)***	251 (3)***	348 (3)***	411 (3)***	459 (3)	496 (6)	506 (17)

[1]Fishery Management Information Systems (1991).

*** Indicates significance at $P < 0.001$.

Table 7. Relationship of available prey/predator ratio to relative weight (Wr) of largemouth bass in Lake Ashbaugh.

Length Class (mm)	1989[1]		1991[2]		1992[3]	
	AP/P	Wr	AP/P	Wr	AP/P	Wr
201-225	7.82	93	3.50	83	1.20	81
226-250	7.49	93	1.15	85	0.56	82
251-275	6.15	89	1.25	87	0.70	80
276-300	6.53	93	0.46	88	0.58	78
301-325	7.17	95	0.69	90	0.78	80
326-350	6.63	93	0.88	84	0.98	82
351-375	6.32	98	1.16	95	1.26	84
376-400	5.63	95	1.60	89	1.86	ND
401-425	6.32	100	2.10	88	2.48	ND
426-450	5.88	96	2.06	78	2.73	81
451-475	6.04	112	2.09	ND	2.84	ND
476-500	6.24	106	2.13	83	2.93	83
501-525	6.52	105	2.18	ND	2.95	93
526-550	6.78	137	2.31	ND	2.99	ND
551-575	6.97	115	2.30	98	3.05	ND
576-600	7.41	127	2.58	ND	3.37	95
Corr. Coef. (r):	(-0.16, $P < 0.60$)		(0.20, $P < 0.55$)		(0.74, $P < 0.01$)	

[1]Roberg and Henry (1989).
[2]Barkley and Henry (1991).
[3]Barkley and Henry (1992a).

mm studied in Oklahoma and Texas were significantly greater than those of the present study {$P < 0.01$} (Wright and Wigtail, 1980; Maceina and Murphy, 1988).

Prey Availability.--An adequate forage base along with a balanced population is essential to condition, recruitment and overall growth of a LMB population (Heidinger, 1975). There were numerous younger LMB, with 81 % of the total population measuring between 200 mm and 380 mm. There was poor recruitment of LMB into size classes larger than 380 mm and slow overall growth for the entire sample population of Lake Ashbaugh, resulting in very low potential harvest rates by fisherman on Lake Ashbaugh.

The major prey species for largemouth bass of Lake Ashbaugh are gizzard shad {51.5%} (*Dorosoma cepedianum*) and bluegill {25.9%} (*Lepomis macrochirus*) (Barkley and Henry, 1992a). Gizzard shad have the ability to quickly grow through the size range where they are vulnerable to largemouth bass in the population (Kirk and Davies, 1985). If the largemouth bass cannot adequately control the numbers of shad within a reservoir, the shad can reduce the carrying capacity of the lake for LMB through competition for available food. This lack of population control is evident as 99.7% of the shad population biomass was adult-sized, rendering them unavailable as prey (Barkley and Henry, 1992a). Recruitment of bluegill has also been poor for the past several years due in part to the high numbers of young LMB feeding on young of the year bluegill (Barkley and Henry, 1991; Barkley and Henry, 1992a). Gizzard shad feeding on bluegill eggs and juveniles compounds this problem (Kirk and Davies, 1985).

Food availability can be estimated by available

Age, Growth and Condition of Largemouth Bass, *Micropterus salmoides*, of Lake Ashbaugh, Arkansas

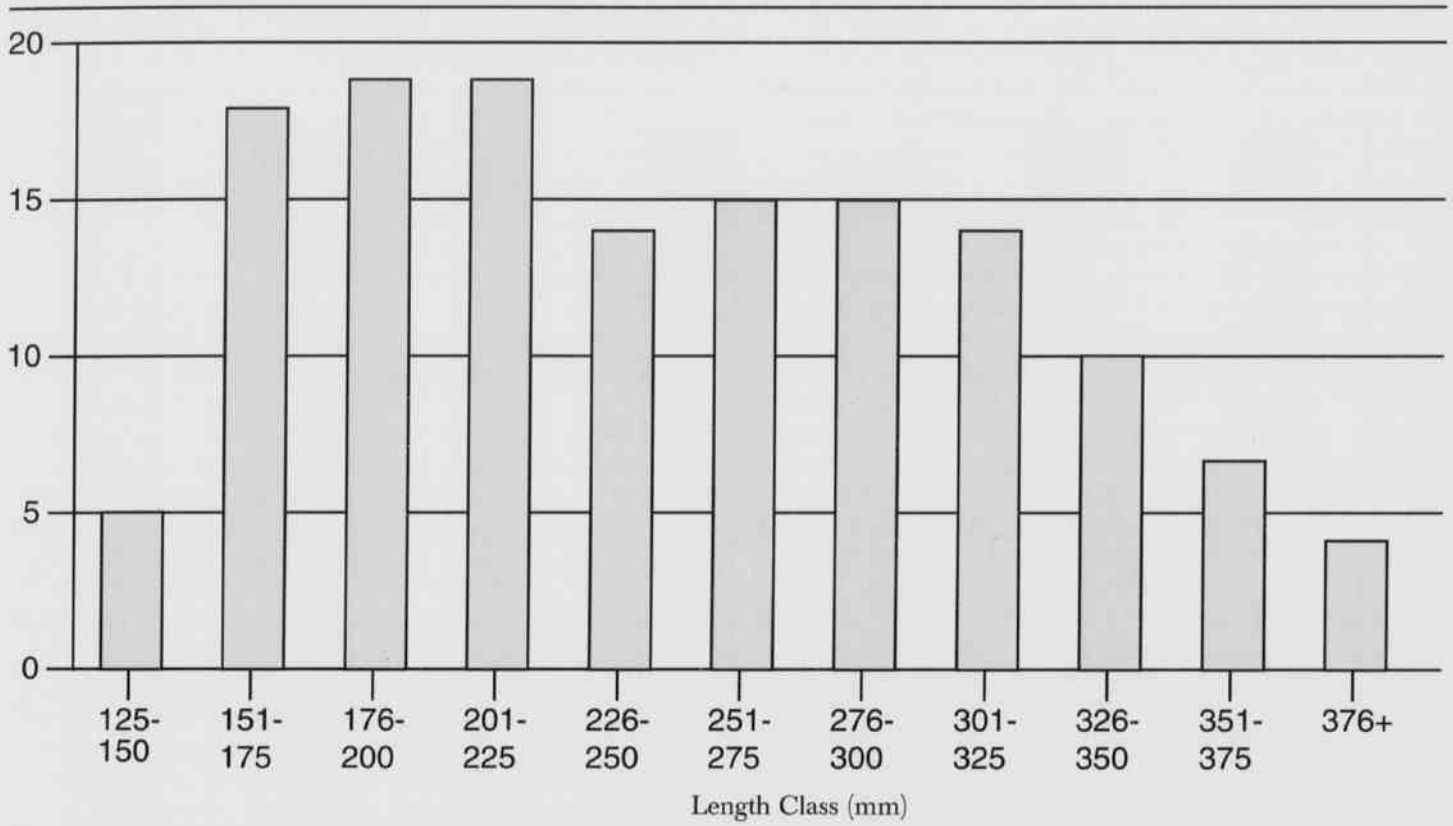

Fig. 1. Length frequencies for LMB of Lake Ashbaugh for 1992.

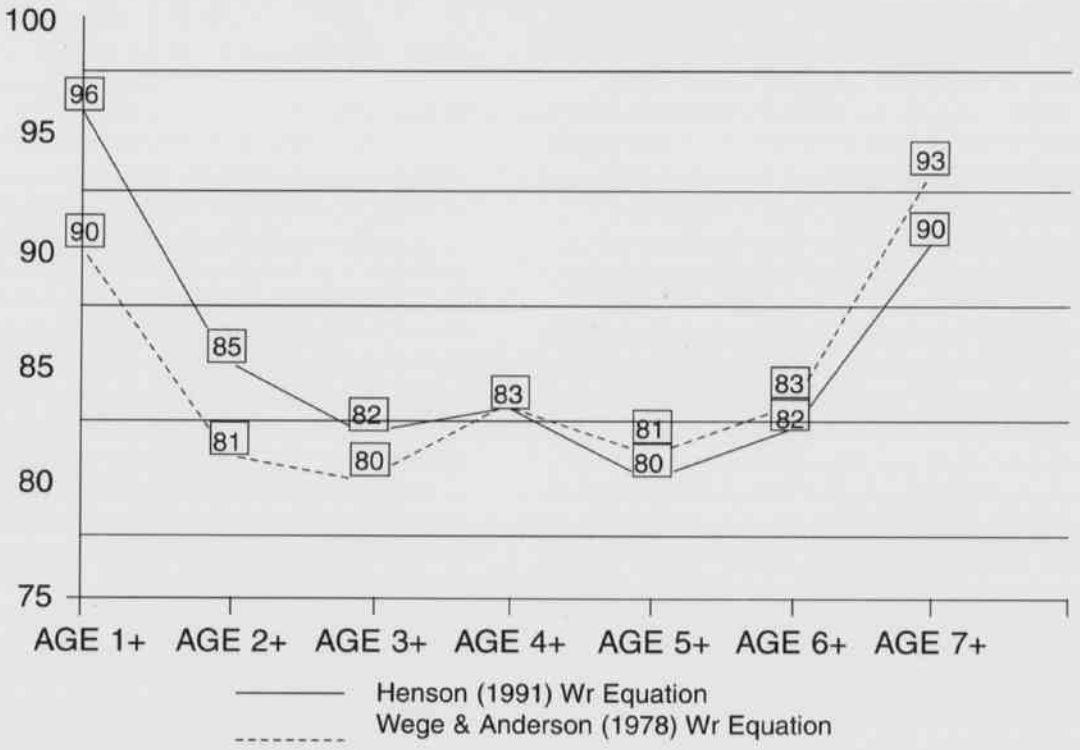

Fig. 2. Mean relative weight for different age groups of LMB in Lake Ashbaugh.

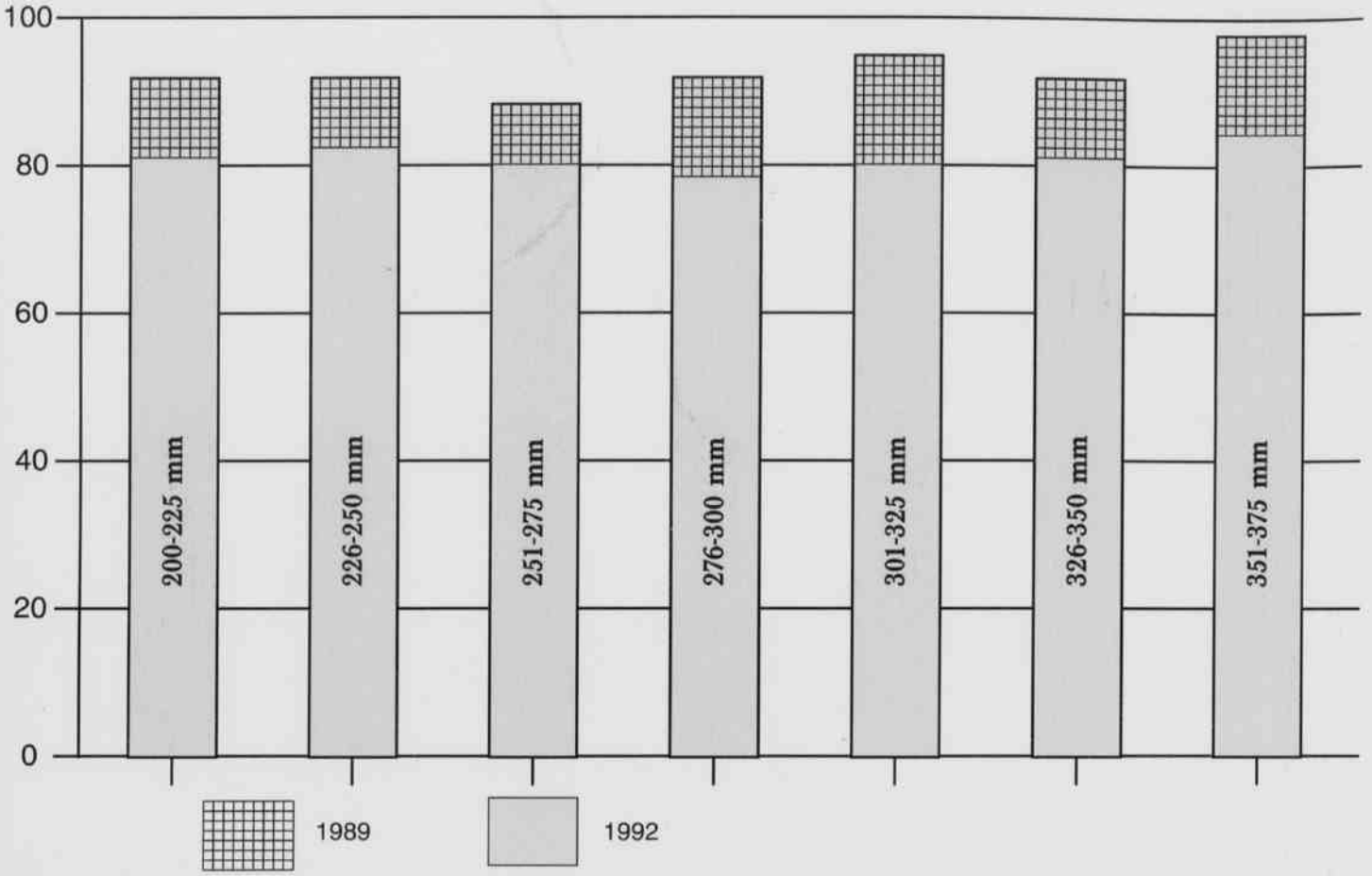

Fig. 3. Mean relative weights for LMB size classes for the years 1989 and 1992.

prey/predator (AP/P) ratios calculated from rotenone sampling. The optimal AP/P ratio is generally considered to be 1.0 (Jenkins and Morais, 1978). The AP/P ratios for all size classes of Lake Ashbaugh LMB have continually decreased since 1989 (Table 9). In 1989 there was abundant forage for all size classes, which is reflected by higher relative weight values for each length class (Roberg and Henry, 1989). The AP/P ratio was well below 1.0 for several size classes (226-325 mm) in the present study, indicating an inadequate forage base for bass of those size classes (Barkley and Henry, 1991). The high number of younger LMB and the low availability of prey have contributed to the poor condition of largemouth bass in the 1992 sample. Condition was significantly correlated to the AP/P ratio in the 1992 population, yet not for the years 1989 and 1991 (Table 9). This low availability of prey may be due to the prey being quickly consumed prior to their growing large enough to sustain a quality largemouth bass population.

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Assessing the Cost of Best Management Practices in Arkansas

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Abstract

A geographic information system (GIS) is a set of powerful, computer-based, analytical algorithms for solving spatial data problems. Recently, due to increases in memory size, computing speed, and programming advances, personal computers have been used in spatial analysis problems. This study reports the benefits of using a PC-based GIS system to solve a common, but complicated problem in forest management: assignment of harvesting areas with harvesting exclusion zones. Two stands each from the USDA Crossett Experimental Forest, the University of Arkansas Forest, and the Ouachita National Forest (total six) were analyzed to determine the changes due to following best management practices (BMPs) and by excluding sensitive areas from harvesting activity with stream-side management zones (SMZs). A onetime loss land, averaging seven percent of the forest land, was taken out of production due to the implementation of SMZs. Benefit cost ratios of harvestable timber value to harvesting cost decreased with the imposition of SMZs, but the judicious use of portable bridging to span SMZs at critical locations mitigated losses significantly.

Introduction

Geographic information systems (GIS) provide a powerful set of computer based analytical algorithms that may be used in solving spatial data problems. In addition to their conventional mapping capabilities, GIS programs can solve difficult spatial allocation problems that do not lend themselves to traditional intuitive solutions (Weih and Hutchins, 1993). These include problems that are too complex mathematically to be attacked by plane or solid geometry or operations research methods. More recently, GIS programs have become available for PC-based DOS and Windows operating environments. This paper reports the use of one such program, IDRISI (Clark Labs, 1995), in a land classification problem and an operating cost problem associated with the implementation of best management practices (BMPs).

Problem Statement.--BMPs have been instituted for a variety of reasons including stream and watershed protection. Decreased stream turbidity due to reduced skidding perturbations, decreased insolation with associated rises in stream temperatures, and protection of faunal habitat are all direct benefits from SMZ setasides (Foreman, 1995). However, there are two management costs associated with SMZs. First is the one-time loss in productive area for growing trees because of land taken out of, or partially out of, the normal productive land base. The second problem is the increased operational cost of harvesting because equipment must go around SMZs, thereby extending skidding distances. It is commonly believed that restrictions on machine operational mobility result in sub-optimization of the harvesting plan and significantly greater total harvest cost.

Methodology

Using GIS in Land Classification.--GIS analysis starts with thematic layers of information that are overlaid to produce maps. These maps contain information that may be manipulated to answer management questions. For example, Fig. 1 shows a 68.4 hectare tract (Crosl) that is bounded on four sides by roads, and a stream, with its associated SMZ flowing through it. We specified the SMZ width as 20 meters on each side of the stream. Additionally, there are four assigned landing zones. GIS algorithms have the ability to sum the pixels in each land use category and to print out a report of their frequency (Clark Labs, 1995). Table 1 shows the allocation of area by land use. For the six stands we analyzed, SMZs occupied 3%, 4%, 8%, 8%, 8%, and 10%, for an average of 7%. While 7% does not appear to be a large proportion of the total area to remove from the productive land base in exchange for the ecological benefits obtained, the actual loss is slightly greater. For example, in Cros 1, the pre-SMZ area usable for growing trees was 60.3 hectares (forestland + SMZ). Reducing this area by the SMZ exclusion produces a loss of 9.4% instead of 8.3% when all land on the tract is used as the timber base. Obviously, the percentage of land lost from production will vary somewhat with physiography and stand. The value loss of this exclusion is the value of the periodic series of timber revenues from this land. Additionally, this land is probably of higher

productivity because of higher site index near streams. Clearly, the one-time loss to forest managers in timber producing area is significant.

Using GIS to Determine Changes in Operating Costs.--A Simple Case - Digital elevation models (DEMs) are a fundamental building block of most GIS analysis. DEMs give immediate clues to the "lay of the land". When DEMs are overlain with thematic layers for roads and hydrology, a map that is usable for operational analysis emerges (Fig. 2). Figure 3 is a cost surface which depicts the two-way cost to skid timber from each pixel of the 68.4 hectare tract to the closest landing. This surface is calculated by taking the sum of individual pixel travel costs from each pixel to the nearest landing zone. A "cost-shed" is produced. This is the optimal geometric solution. There is an operational assumption of no restriction on skidder movement in this solution. An additional algorithm sums the individual cell costs yielding total skidding cost for the tract. However, when we impose the SMZs demonstrated in Fig. 1 on this tract, the total skidding cost is increased significantly (Fig. 4). Additionally, because in this demonstration, there is a "non-penetration" restriction on the SMZ, the assignment of individual pixels to landing zones is sub-optimal compared to the optimal geometric solution (Fig. 3). In this scenario SMZ penetration was prevented by assessing an exorbitantly high pixel travel cost to the pixels in the SMZ.

Harvesting engineers wrestled with the problem of SMZ crossings for a number of years before portable bridges came into wide-scale use (Blinn et al., 1996). The advantages of portable bridges include keeping skidders out of streams, reduced turbidity, concentrating stream-crossing traffic at controllable points, re-usability and the relatively low cost of these structures (Blinn et al., 1996; Bates, 1995; Tornatore, 1995). Disadvantages include increases in set-up time and a requirement to prepare bridge approaches within the SMZ (Blinn et al., 1996; Bates, 1995).

To determine whether bridging the SMZs was operationally cost efficient, the SMZ pixel travel cost was successively reduced until it became cheaper to incur this cost than to go around the SMZ or to haul directly to the nearest non-SMZ-restricted landing zone. The locations on the SMZ where crossings occurred were designated as bridge locations and the total skidding cost for all pixel locations was computed. As SMZ pixel travel cost was successively lowered, more SMZ penetrations occurred and more bridges were installed. This process continued until the SMZ pixel travel cost converged with the estimated bridge two-way pass cost. This value was developed from published information about portable bridge cost and expected life, based on traffic and wear (Blinn, 1996). Figure 5 shows the locations of five bridges placed on the tract. Note that the lines delineating the allocation of each pixel to a landing zone approach the optimal geometric solution depicted in Fig. 3.

Table 2 shows the cost to skid for the demonstration tract under the three different scenarios of no restrictions (no SMZ), SMZ restrictions and SMZs with bridges. Note that the cost to skid with the SMZ is lower than with no SMZs imposed. This is due to the 5.7 hectare reduction in total area (that went from forest land into the SMZs) that must be skidded. However, note also that there is a reduction in total cost attributable to using the bridges. Figure 4 shows the locations of five bridges on the tract. Note that the lines delineating the allocation of each pixel to a landing zone approaches the optimal geometric solution depicted in Figure 2.

Stream Locked Areas.--Figure 6 depicts a tract (POW1) on which there are two streamlocked areas. This land-use-allocation map, similar to Fig. 1, shows a road with an associated landing zone and a stream. Note that there are two stream-locked areas: one in the inter-stream confluence and a second, north of the stream. These areas are inaccessible under the SMZ impenetrability restriction. However, when bridges are located using the travel cost reduction technique, two bridges are placed, and subsequently, a much larger area becomes accessible (Fig. 7).

Harvest Values.--Table 2 shows the cost to skid and the harvestable timber values for the two demonstration tracts under the three different scenarios of no restrictions (no SMZs), SMZs with restrictions, and SMZs with bridges. Skidding cost was established through an algorithm established by Kluender and Stokes (1996). Timber land was uniformly valued at $2,966 per hectare based on an assumption of 9.9 thousand board feet of timber per hectare times a market price of $300 per thousand board foot. While this

Table 1. Allocation of area in the 68.4 hectare study tract, by land use.

Use	Area	% of area
Forest land	54.6	79.8
Roads	6.9	10.1
SMZ	5.7	8.3
Landing zones	1.2	1.8
Total area	68.4	100.0

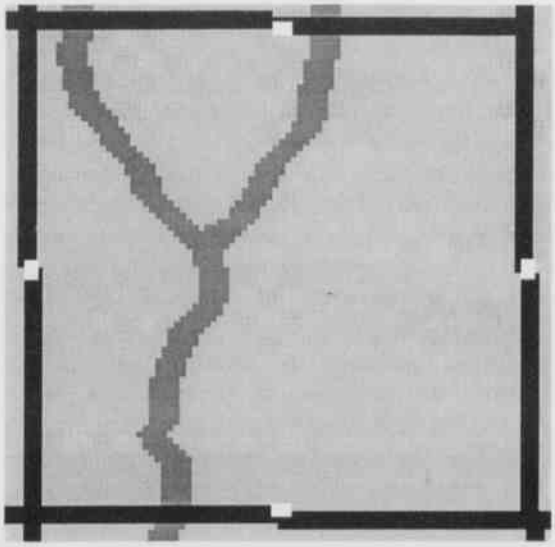

Fig. 1. Land use allocation map for the 68.4 hectare tract (Cros1).

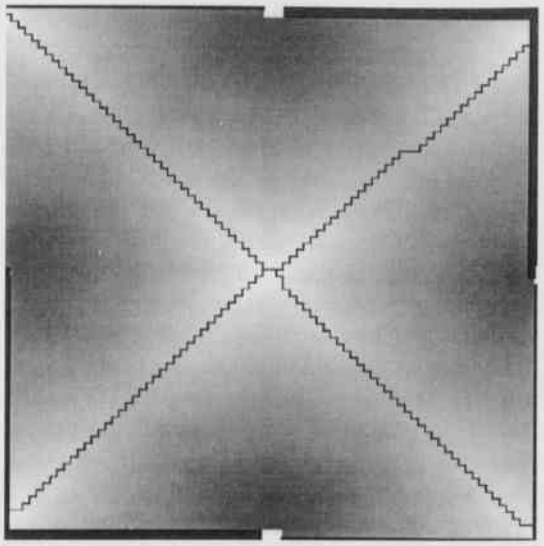

Fig. 3. Optimal geometric harvesting cost model for the Cros1 tract.

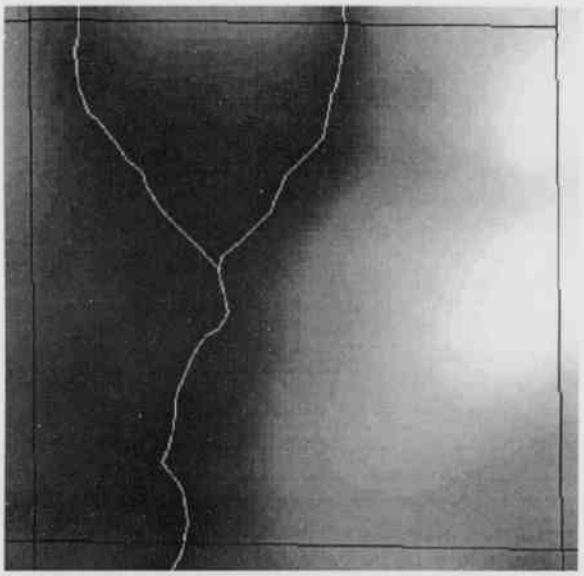

Fig. 2. Shaded digital elevation model (DEM) with roads and hydrologic features for the Cros1 tract.

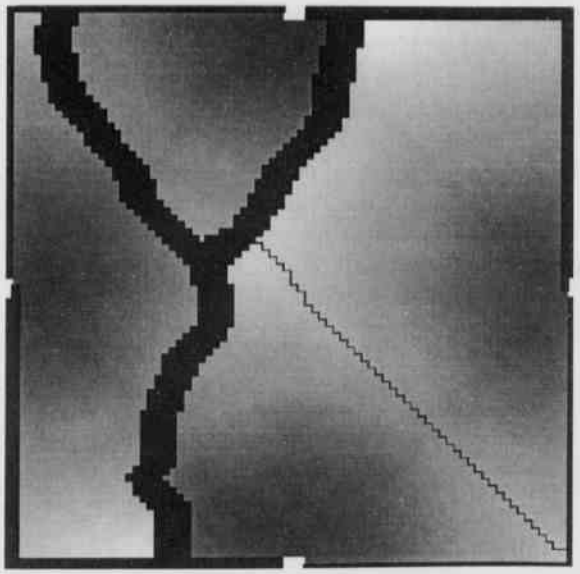

Fig. 4. Sub-optimal harvest layout required by the SMZ non-penetration requirement for the Cros1 tract.

perhaps produces a conservative per-hectare estimate, it yields a number that may be compared across several tracts.

Skidding cost with no SMZ is the optimal harvesting configuration. The cost to skid with the SMZ impenetrability restriction includes the opportunity cost of the unharvestable timber that is tied up in the SMZ itself, and in the stream locked areas. The cost to skid when the SMZ's are bridged includes the cost to skid and the cost of timber tied up in the SMZ. Value for the no-SMZ scenario is the total value of the tract. Value for the tracts when SMZs are in place includes all accessible timber (not in an SMZ or stream-locked area). Timber value for the SMZ-with-bridges scenario included all timber on the tract except for that reserved into the SMZs.

Benefit/Cost Relations.--One way to better understand the relation between value loss and costs concurrent with the addition of SMZs (Table 2) is the use of benefit/cost ratios (B/C) (Gregory, 1987). To demonstrate shifts in B/C

Table 2. Cost to skid and associated timber values ($) for the 68.4 hectare and the 57 hectare tracts under three harvesting conditions.

	68.4 Ha. Tract (Cros1)				57.0 Ha. Tract (POW1)			
	Cost	Timber Value	B/C Ratio	Marginal B/C Ratio	Cost	Timber Value	B / C Ratio	Marginal B/C Ratio
No SMZ	49,216	178,060	3.62		53,729	165,220	3.08	
SMZ Restriction	62,226	161,633	2.60	0.72	99,959	95,005	0.95	0.31
SMZ With Bridges	61,225	161,633	2.64	1.02	67,544	148,200	2.20	2.31

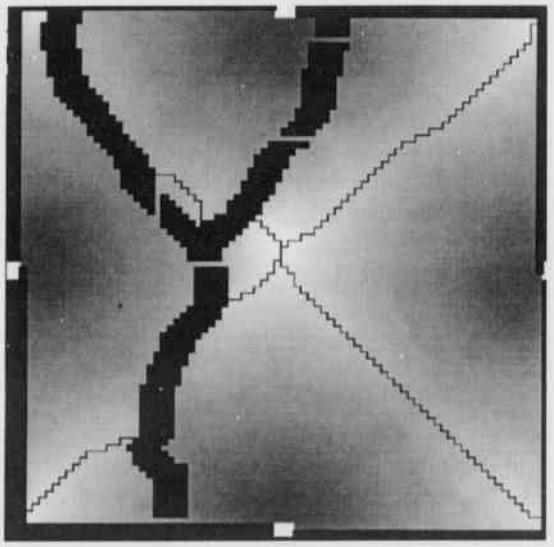

Fig. 5. Near optimal harvesting layout depicting bridge locations for the Cros1 tract.

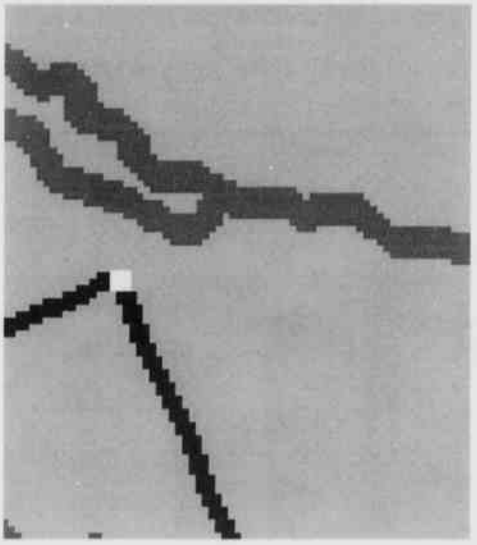

Fig. 6. POW1 tract showing near optimal harvest layout with two bridges.

ratios, Fig. 8 depicts the B/C ratios for the six tracts that we studied (including Cros1 and POW1 described above). A better understanding of the problem is provided, first, by realizing that all B/C ratios are strongly positive; in all cases examined, the timber is worth many times more than its retrieval cost. Second, additional understanding is gained by comparing the B/C ratios in moving from the no-SMZ to the SMZ scenario and from the SMZ to bridged SMZ scenario (Fig. 9). This statistic takes on the quality of an elasticity or marginal B/C ratio (Gregory, 1987). It summarizes the loss in the move from unrestricted movement to the restrictions of the SMZ and then, the benefit of adding the bridges to the SMZs to relieve movement restrictions. For all tracts the B/C ratio of going from unrestricted movement to the SMZ restrictions is less than one. In other words, there is always some loss inherent in SMZ placement. Minimal losses were associated with tracts where only the SMZ area was lost, and very little additional harvesting cost was incurred. In these cases, the marginal B/C ratio of adding the bridge was only slightly higher than 1.0. In situations were significant area is stream-locked by the SMZ, the marginal B/C ratio associated with adding a SMZ is very low (<0.5). However, in these cases the marginal B/C of adding bridges was very high, close to 2.5. However, this condition will only exist where significant areas are isolated by SMZs. Under these circumstances, product prices and harvesting costs become more important in the decision about bridging and accessing areas of a tract that are marginally accessible

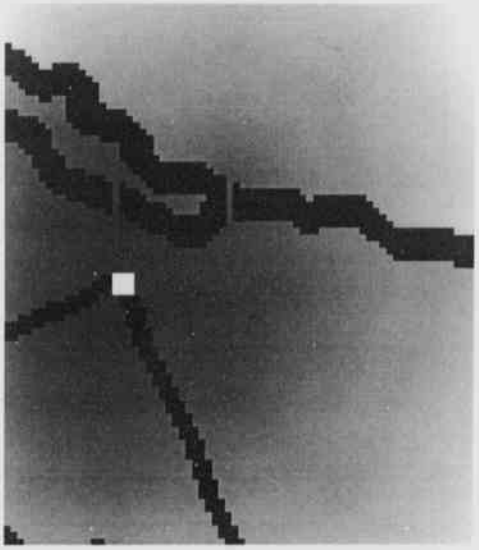

Fig. 7 POW1 tract showing near optimal harvest layout with two bridges.

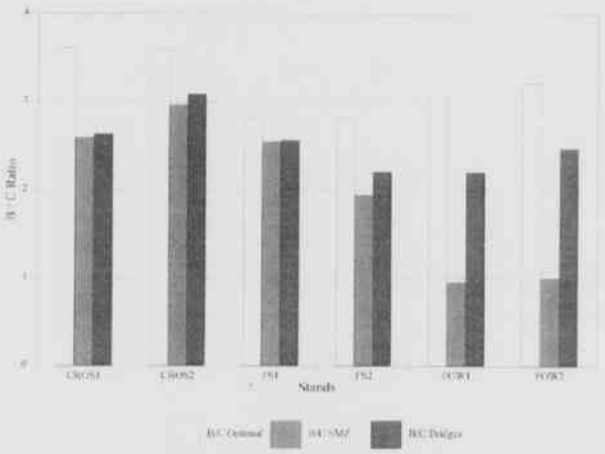

Fig. 8. Benefit / Cost ratios for the optimal harvest solution, SMZ restricted harvesting and bridged SMZs for six study tracts.

at best.

Conclusions

This study demonstrates that PCs and PC-based GIS software can be used effectively in the solution of spatial analysis problems. Depending on physiography, SMZs may tie up 3 - 10% of the total operating area of a tract. SMZs are formed from that part of a tract allotted to timber production and may be entirely out of production, depending on how the BMP is implemented. SMZs may 'stream-lock' sig-

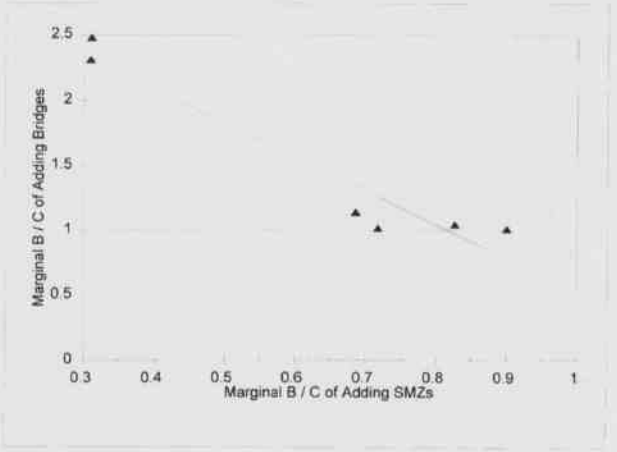

Fig. 9. Marginal B/C ratios for going to bridged SMZ plotted against marginal B/C ratio of adding SMZ restrictiosn for six study tracts.

nificant areas of operational land not actually included in the SMZ itself if non-penetration requirements exist. In situations where the imposition of an SMZ greatly effects operational area and movement, portable bridging to cross the SMZ becomes an increasingly good investment.

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Thin Film Deposition of Silicon for Solar Cell Applications

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Abstract

Thin films of silicon have been formed using a patented electrostatic deposition method which utilizes charged particle motion in an electric field. After deposition, the films are heat treated for varying times and temperatures in a programmable furnace maintained under a purified argon atmosphere. X-ray diffraction (XRD) confirmed that these films were polycrystalline in nature. These films were found to have grain sizes of about 50 microns. Solar cells were fabricated using these large-grained polycrystalline silicon films by sputtering pure gold as both front and back contacts. The cells have shown efficiencies of 1.8%. This paper reports on the growth of these large-grained polycrystalline thin silicon films and on the laser recrystallization setup to be used to increase the grain size up to 100 microns. Films grown via this electrostatic deposition method and subsequent laser recrystallization have a great potential for use in the solar cell industry.

Introduction

Single crystal silicon solar cells are the best known photovoltaic energy converter. Solar cell arrays have been used extensively to supply electric power in spacecraft for many years. The steps involved in the fabrication of these cells are very energy, labor, and material intensive (Chu et al., 1975). Also, the present cost of single crystal silicon solar cells makes their use prohibitively expensive except for applications in space vehicles and as power sources in certain remote areas. (Fan and Zeiger, 1975).

To reduce the material and processing costs, one approach involves the deposition of a thin layer of polycrystalline silicon containing a p-n junction on a suitable substrate (Chu and Singh, 1976). Polycrystalline silicon has great potential for large scale terrestrial photovoltaic device applications. Techniques for preparing polycrystalline silicon are, in general, less critical than those required to produce single-crystal silicon. Also, polycrystalline silicon shows great promise for reducing costs by circumventing many of the complex and energy-intensive steps associated with the growth of single crystals.

An electrostatic deposition process which utilizes charged particle motion in an electric field has been successfully developed as a method for the deposition of silicon films. (Gadepally et al., 1990). In their research, silicon films (coatings) were deposited on conducting, insulating, and semiconducting surfaces after making suitable changes in deposition parameters. These coatings subsequently were heat treated to establish an alternative method to generate polycrystalline electronic-grade silicon with grain sizes from four to ten microns.

This electrostatic thin film deposition technique can offer significant cost reduction in the growth of polycrystalline silicon thin films relative to conventional deposition methods such as sputtering, chemical vapor deposition (CVD), and molecular beam epitaxy.

Several experimental and theoretical results have indicated that there is an increase in efficiency of polycrystalline silicon solar cells with increasing grain sizes (Ghosh et al., 1979). It is generally accepted that grains of at least 100 microns are necessary to make polycrystalline silicon solar cells having efficiencies $> 10\%$ (Ghosh et al., 1979; Ouwens and Heijligers, 1975). If a high-power laser beam is focused on the surface of a silicon film that absorbs at the laser frequency, the film can be locally heated to temperatures high enough to cause crystallization (Fan and Zeiger, 1975). This paper reports on the growth of large grained (> 50 microns < 100 microns) polycrystalline silicon films using the electrostatic deposition method suitable for solar cell applications and on the laser recrystallization setup to be used to increase the grain size up to 100 microns.

Materials and Methods

Thin films of silicon were obtained by depositing 100 mesh electronic-grade silicon powder (purity = 98%) supplied by Cerac Inc. on single crystal silicon substrates supplied by MEMC Electronic Materials, Inc. P and n doped powders doped with boron and phosphorous (dopant level $= 1 \times 10^{15}$ atoms / cm^3 - 1×10^{17} atoms / cm^3) were used. Immediately prior to the deposition, the substrates were given a standard wash in a formic acid - hydrogen peroxide mixture (7:3), rinsed in deionized water, and transferred to 48% hydrofluoric acid for one minute to remove all traces of

oxide from the surface. They then were given a prolonged wash in deionized water and finally blown dry using pure nitrogen (Lillington and Townsend, 1976). The powders were deposited using the electrostatic spray gun at Ameron Powder Coatings in Little Rock, Arkansas. As illustrated in Fig. 1, the silicon powder "S" in particulate form is stored in a hopper that is secured to the top of the gun. The gun has an electrode located at the front end, which is connected to a high voltage generator via an electrical line passing through the gun body. Pressurized dry air is driven through the gun which facilitates the transportation and charging of the silicon particles. The powder "S" is delivered to the gun nozzle by both gravity and a Venturi effect as seen in the detail. When the trigger of the gun is actuated, the silicon powder that is stored in the hopper is drawn into the hopper-Venturi feeder. When the exterior opening of the gun is directed toward a grounded substrate, electric field lines form between the tip of the electrode, extending from the corona region, and the grounded substrate. The charged silicon particles follow the electric field lines, resulting in the deposition of the particles onto the grounded substrate.

The powders were deposited at gun voltages ranging from 60 kV to 80 kV. The input pressure of the gun was varied from 6 bar to 12 bar. The deposition time varied between 2 and 5 seconds. The powders were deposited on both p-doped (resistivity: 1-3 ohm-cm) and n-doped (resistivity: 1-4 ohm-cm) single crystal silicon substrates. The configurations obtained were p/n, p/p, n/p, and n/n.

Heat treatment of these deposited films was carried out in a programmable Lindberg Model 51333 furnace (maximum temperature of 1500°C) for varying times and at different temperatures. The heat treatment times varied from 1 hour to 24 hours and the temperature varied from 600° C to 1370° C. In order to minimize any oxide formation, a filtered purified argon atmosphere was maintained within the furnace, which was modified for the heat treatment as shown in Fig. 2. The opening to the furnace was plugged with an ash and sali insulating material obtained from Zircar Products, Inc.. A hole was drilled through the center of the insulating material to accommodate an alumina process tube which held the samples to be heated. A removable flange having two ports was attached to the process tube. One port was connected to a gas cylinder containing argon; whereas the other port was connected to a vacuum pump. A

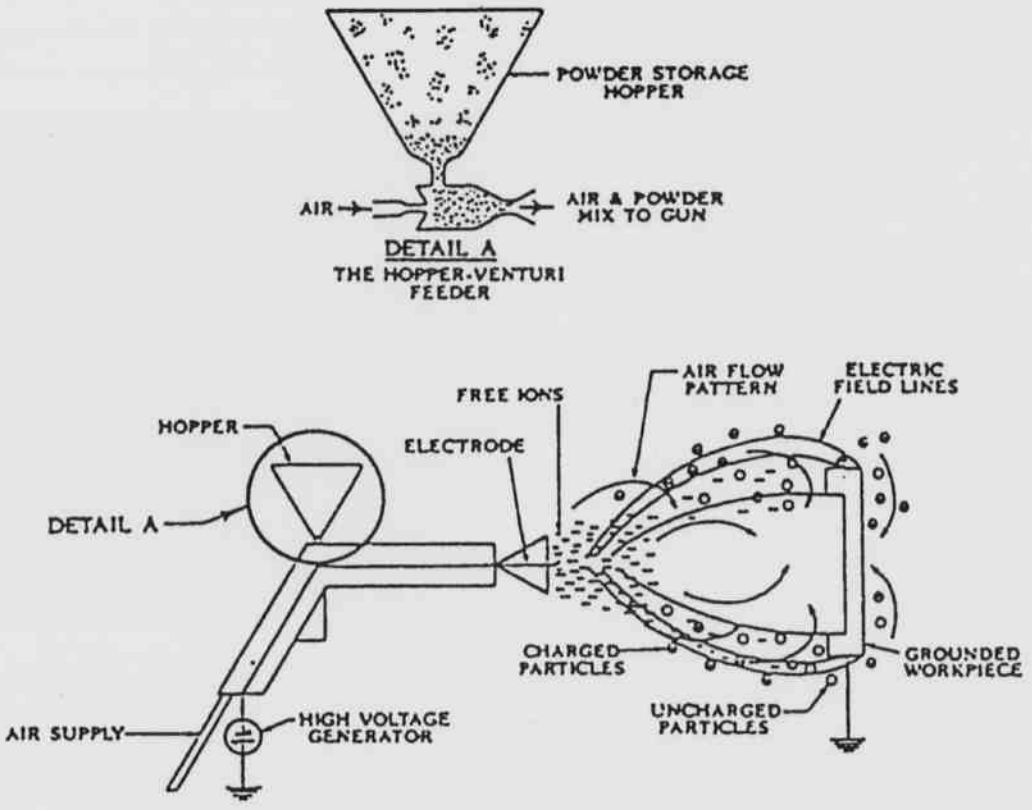

Fig. 1. Schematic of electrostatic spray gun.

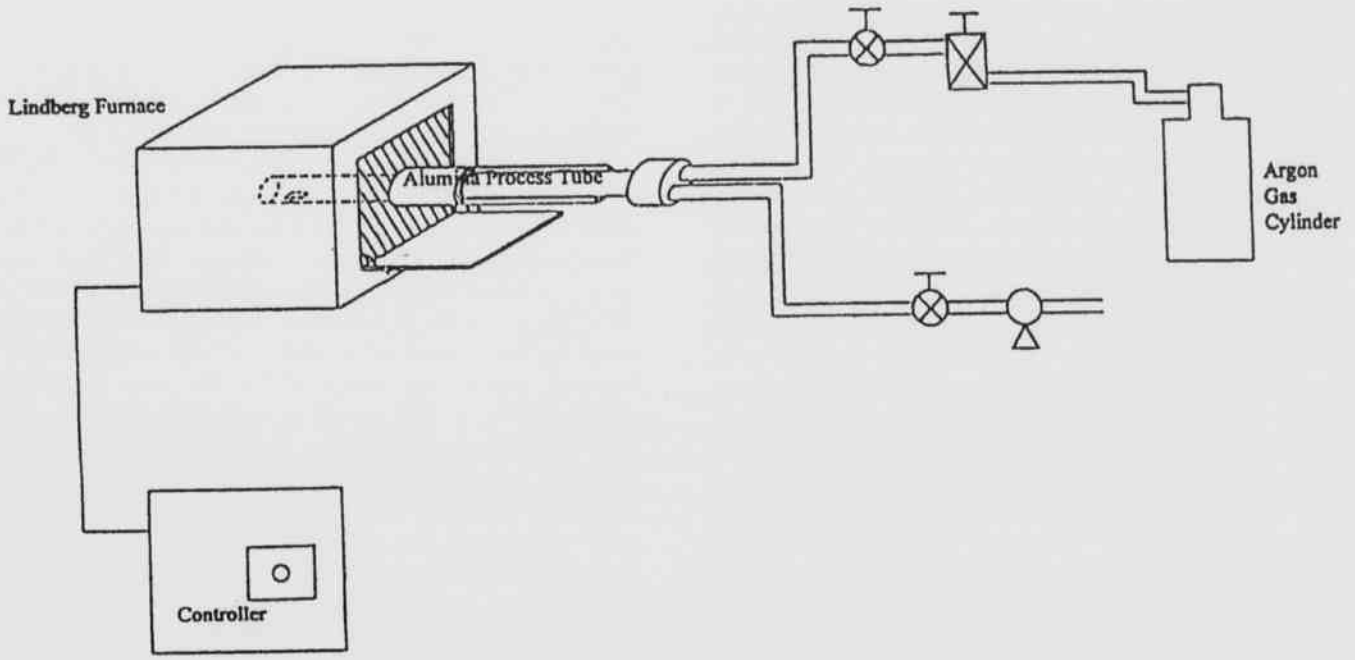

Fig. 2. Schematic of heat treatment apparatus.

Lindberg Model 58125 (818P) controller for regulating the furnace was connected to the furnace via cable wires. Prior to heat treatment, the vacuum pump was turned on to remove all traces of air from the process tube.

The primary recrystallization temperature, which is defined as the temperature at which 98% of the material is recrystallized within 0.5 hours (Ouwens and Heijligers, 1975) was found to be about 1200° C. It must be noted that no further change was observed at that temperature even if the samples were heat treated for more than 24 hours; these films were assessed using a Cambridge Stereoscan 600 Scanning Electron Microscope (SEM). Average grain diameters were found to be about 20 microns. Secondary recrystallization was observed from 1350°C upwards. As usual with secondary recrystallization, when samples are heated for a relatively short time, big grains amidst smaller grains are observed. The big grains are about 60 microns, and the smaller ones about 20 microns (Figs. 3a and 3b). The optimum time and temperature were found to be 10 hours and 1370°C, respectively. The film thickness was found to increase with the increase in the input pressure of the gun. Films deposited at an input pressure of 6 bar had a thickness of around 30 microns, whereas films deposited at an input pressure of 12 bar had a thickness of about 60 microns for a deposition time of 2 seconds. Structure and phase determination was done via X-Ray Diffraction (XRD) using

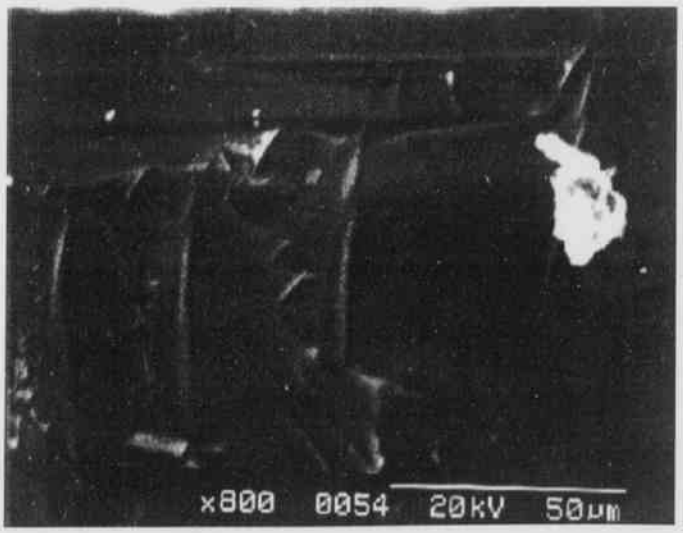

Fig. 3a. SEM photograph of a n/p sample showing average grain size. T = 1370°C, t = 10 hours.

a Philips Model PW 3710 X-Ray diffractometer. A Cu Kα radiation operating at 45 kV and 40 mA was used. The

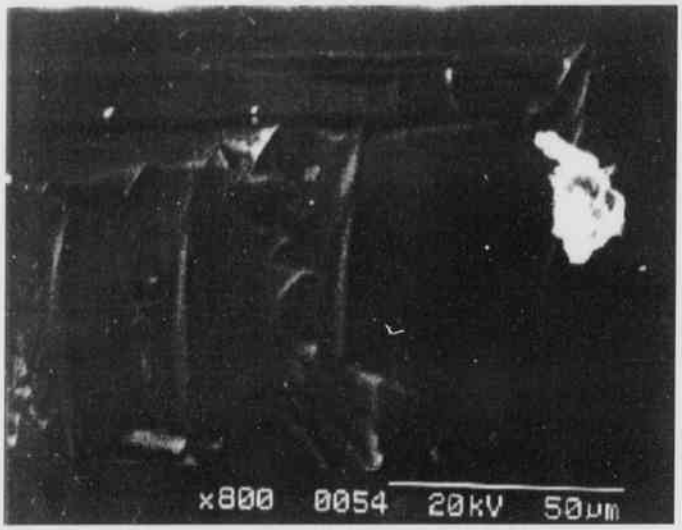

Fig. 3b. SEM photograph of a p/n sample showing average grain size. T = 1370°C, t = 10 hours.

wavelength used was 1.5406 Angstroms. The Bragg angle (θ) was fixed at 12° and the detector (2θ) was scanned from 25° to 90°. The XRD spectrums (Figs. 4 and 5) confirmed the film which was formed to be polycrystalline in nature with sharp <111>, <220>, and <311> peaks. The <111> phase was the most dominant phase.

Solar cells were fabricated by sputtering pure gold as both front and back contacts on the cells having the configurations p/n and n/p. The dark and illuminated I-V characteristics (Fig. 6) of these cells were analyzed using a Tektronix Model 576 curve tracer. The open circuit voltage was found to be about 320 mV, the short-circuit current was found to be about 9 mA. The conversion efficiency was calculated using the standard equation given by

$$\eta = \frac{V_{oc}.I_{sc}.FF}{P_{in}} \times 100,$$

where,

η = Efficiency,
V_{oc} = Open-Circuit Voltage,
I_{sc} = Short-Circuit Current,
FF = Fill Factor, and
P_{in} = Input Power.

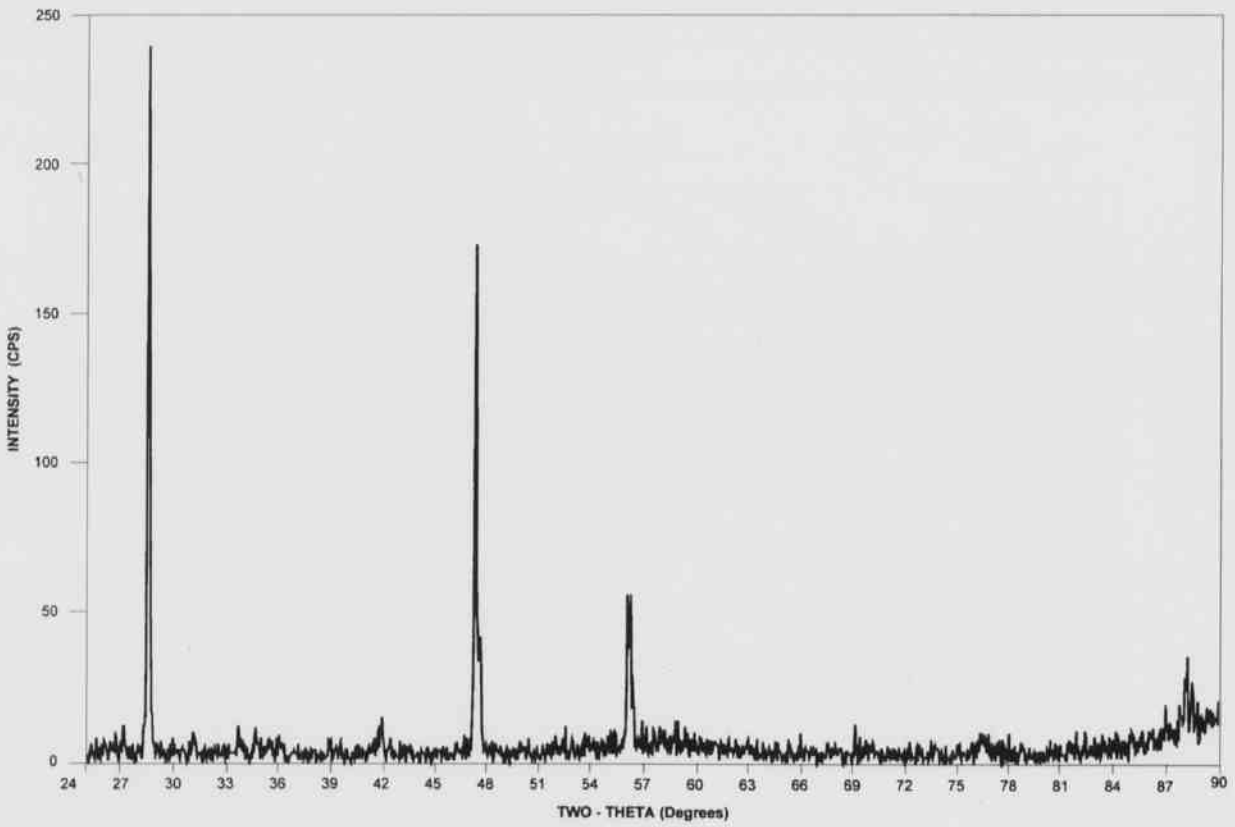

Fig. 4. XRD spectrum of n/p sample. T = 1370°C, t = 10 hours.

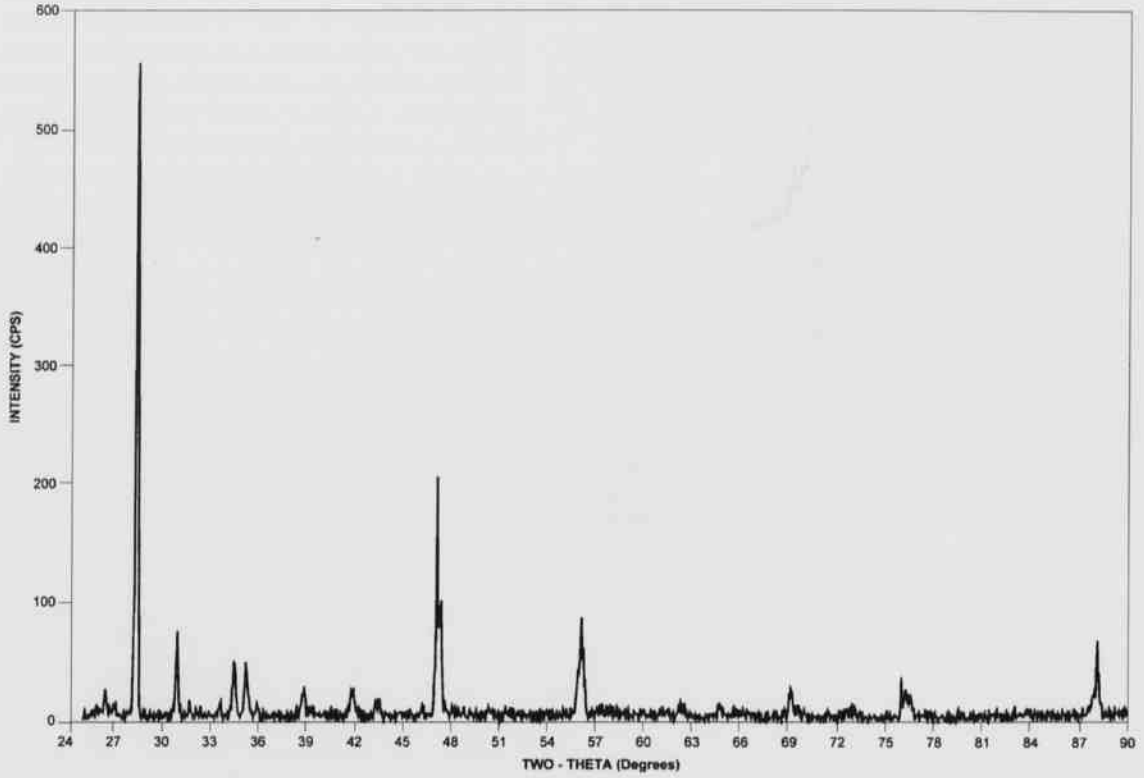

Fig. 5. XRD spectrum of p/n sample. T = 1370°C, t = 10 hours.

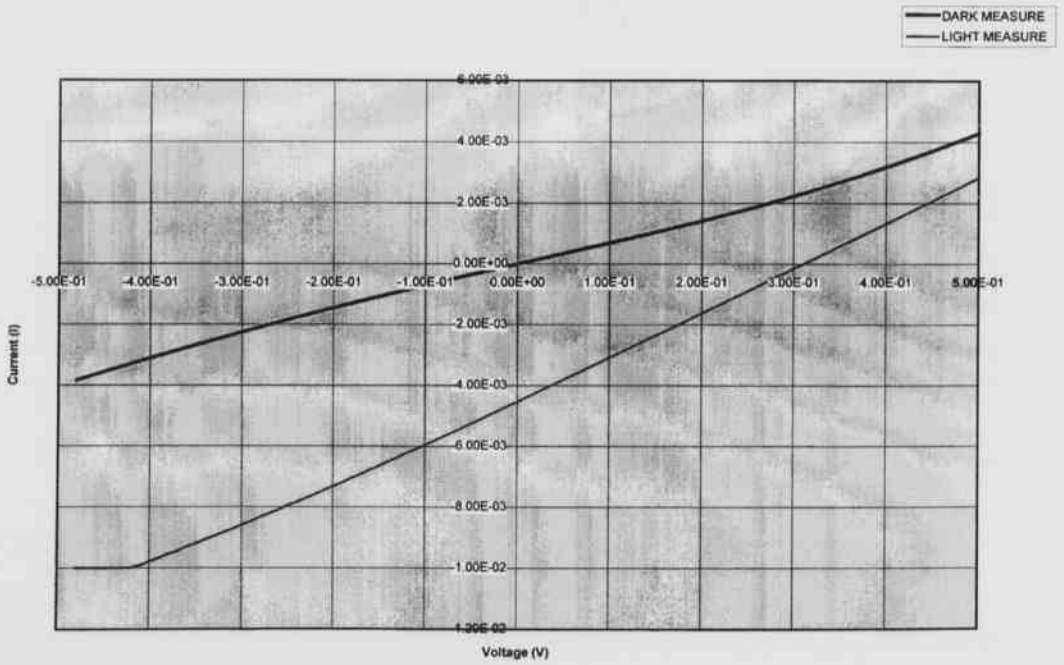

Fig. 6. Dark and illuminated I-V characteristics of fabricated solar cell. 5 mA per vertical division; 100 mV per horizontal division.

The efficiency was found to be about 1.8%. This efficiency can be improved by increasing the grain size to about 100 μm (Ghosh et al., 1979; Ouwens and Heijligers, 1975).

Laser recrystallization produces crystallites whose structure and electrical characteristics vary according to the starting material and the laser scan parameters. Generally, the crystallites nucleate in the surface region and are randomly oriented. A translatable stepper-motor-controlled vacuum stage was designed and constructed for use during laser recrystallization. A CW argon ion laser (Optilase Contact Laser System:Model 900) having total output power of 12 watts and operating at a wavelength of 488 nm is being used.

The sample during the laser recrystallization process will be mounted on a substrate holder made up of tantalum (Fig. 7). The tantalum foil is mounted on a 6 mm thick Macor ceramic block. The substrate holder is enclosed in an aluminum housing. In order to minimize any oxidation, an argon atmosphere will be maintained within the housing.

The substrate will be held at a temperature of about 450° C by heating the tantalum foil using brass strips connected to the foil.

The aluminum housing with the substrate holder will be mounted on the stepper motor controlled x-y stage. Stepper motors operating at 12 V DC, .16 A, and capable of producing 1.8° / step are being used. A complete block diagram of the laser recrystallization setup is shown in Figure 8. Since the optimal conditions for the recrystallization process were not known at the outset, a versatile computer program was written to drive the motors. The x-scan rate using these motors can be varied from 0.1 second to 2 seconds. The sample is scanned linearly which produces overlap regions where non-uniform growth of crystallites may occur.

The next phase of the research will be concentrated on finding the optimum conditions for the laser recrystallization including the laser power, scan rate, and substrate temperature.

Conclusions

Polycrystalline silicon films having grain size > 50 microns have been successfully formed using the electrostatic deposition method. These films were all observed to form at and above a temperature of 1350°C with a constant heat treatment time of 10 hours. Solar cells having efficiencies of 1.8% have been fabricated using these films. Laser recrystallization of these films will be used to increase the grain size up to 100 microns. This fabrication procedure holds great potential in the solar cell industry. This method has the potential to produce large area terrestrial devices at greatly reduced costs.

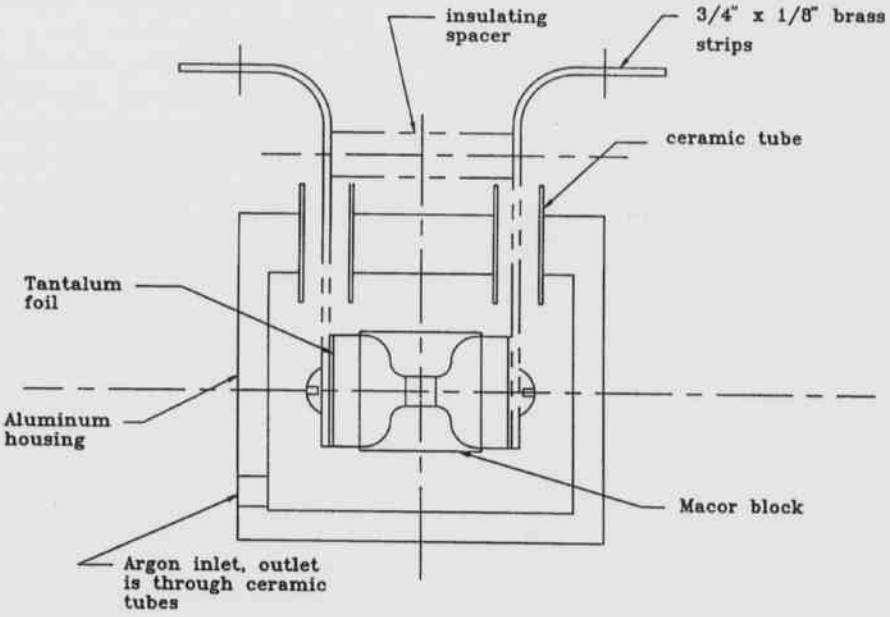

Fig. 7. Diagram of substrate holder.

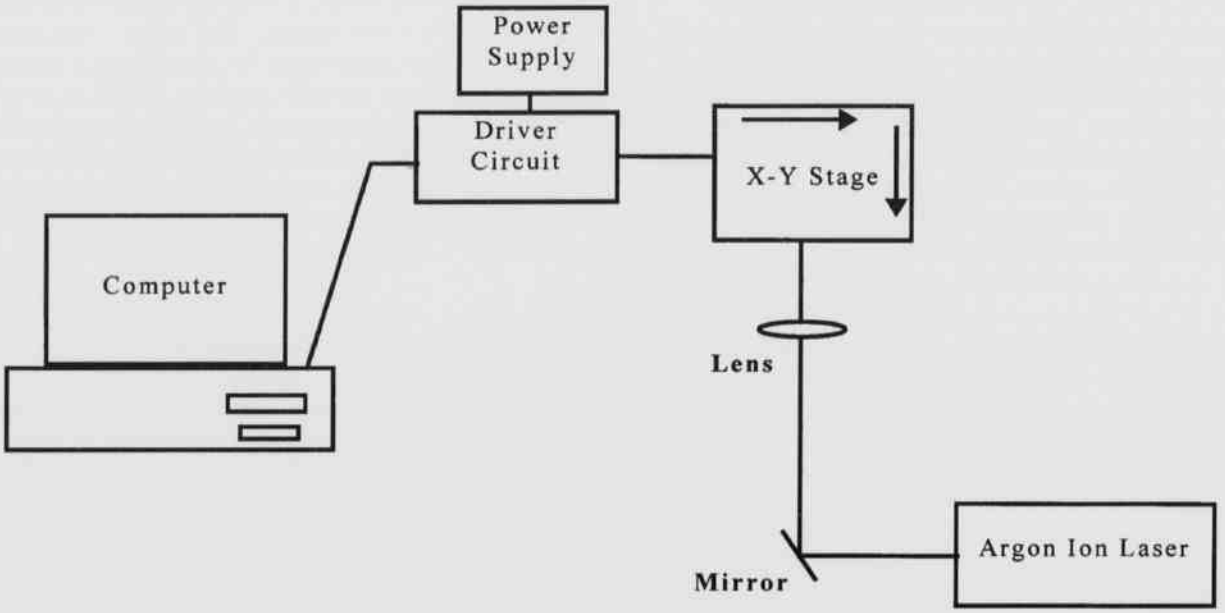

Fig. 8. Laser recrystallization setup.

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Factors Affecting Transformation Efficiency of Poplar Hybrid Line NC5331 by *Agrobacterium tumefaciens*

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Abstract

Acetosyringone, pH, and glucose, which may affect *Agrobacterium*-mediated gene transformation to poplar hybrid line NC5331, were investigated in an attempt to raise the gene transfer efficiency. The *Agrobacterium tumefaciens* strain used harbored a disarmed vector (pMON9749) carrying a β-glucuronidase gene and a kanamycin resistant marker. With the addition of acetosyringone at 25 to 75 μM, the transformation efficiency was significantly enhanced, but dependent on pH. Acetosyringone required a pH above 5.8 to achieve an efficient gene transfer and failed to enhance the transformation at lower pH. However, with addition of both acetosyringone and glucose, the transformation was not affected by pH. We conclude that optimizing transformation conditions may be very critical for a specific plant species and/or the *Agrobacterium* strain.

Introduction

Agrobacterium tumefaciens has the ability to transfer and insert foreign DNA into a cell genome in many dicotyledonous and some monocotyledonous species. *Agrobacterium*-mediated gene transfer can be affected by phenolic signal compounds, monosaccharides, pH, and phosphate concentration. Phenolic compounds, such as acetosyringone, serve as signal molecules which are required to induce the expression of virulence genes of *A. tumefaciens* (Bolton et al., 1986; Ashby et al., 1988). A low concentration of acetosyringone synergistically induces the expression of virulence genes with certain sugars, such as glucose or galactose (Cangelosi et al., 1990; Shimoda et al., 1990). In addition, a pH of less than 6.0 has been suggested to achieve a high level of induction in the presence of phenolic signal compounds (Stachel et al., 1986).

Agrobacterium-mediated gene transfer and regeneration have been achieved in aspen hybrids, *Populus alba* X *P. tremula* and *P. alba* X P. *grandidentata* (Fillatti et al., 1987; De Block, 1990) and poplar hybrid, *Populus trichocarpa* X P. *deltoides*, (Parsons et al., 1986; De Block, 1990). In the present study, we used a poplar hybrid line NC5331 as a model to determine the optimum ranges of acetosyringone concentration and pH and the effect of glucose with the addition of acetosyringone on *Agrobacterium*-mediated gene transformation in an attempt to develop a rapid, reproducible and efficient gene transfer system in poplar hybrids.

Materials and Methods

Bacterial Strain and Its Preparation.--*A. tumefaciens* strain ASE9749 harboring a disarmed vector - pMON9749 (obtained from Monsanto Co., St. Louis, MO) was used in the present study. The plasmid vector carries a β-glucuronidase (GUS) gene and a kanamycinresistant selection marker. Streaked bacteria were grown for 2 days at 28°C on Luria agar (10 g/liter tryptone, 5 g/liter yeast extract, 10 g/liter NaCl and 12 g/liter agar) containing 50 mg/liter kanamycin, 75 mg/liter spectinomycin and 25 mg/liter chloramphenicol. A single colony was then inoculated in LB medium (10 g/liter tryptone, 5 g/liter yeast extract and 5 g/liter NaCl). The liquid culture was grown with shaking at 28°C overnight. This overnight culture (0.5 to 1 X 10^{10} cells/ml) was diluted 50 times with the LB liquid medium supplemented with 0 to 75 μM acetosyringone (Aldrich Chemical Co., Milwaukee, WI) and 10 mM D-glucose (if indicated). The pH was adjusted to a range from 5.5 to 6.4 depending on experiments. To induce expression of virulence genes, the diluted bacterial cultures with aceosyringone were further grown with shaking for 3 h at 28°C before being co-cultured with plant materials.

To determine the correlation between the bacterial growth and possible pH changes, the bacteria were cultured in LB medium (containing 0 to 25 μM acetosyringone and 0 to 10 mM glucose at pH 5.5, 5.8 and 6.1) at 28°C with shaking up to 48 h. The absorbance of bacterial culture density

was measured after 0, 3, 6, 16, 24 and 48 h of incubation at 600 nm with an UV-Visible Recording Spectrophotometer (UV-160U, Shimadzu Scientific Instruments, Columbia, MA). At the same time, pH changes were monitored with a pH meter (model 140, Corning, Corning, NY). Each measurement of optical density (OD) or pH included minimal two replications.

Plant Materials and Transformation Procedures.--The poplar hybrid line NC5331 (*Populus nigra* L. var. *betulifolia* Torr X *P. trichocarpa* Torr and Gray, from the USDA Forest Services, North Central Forest Experiment Station, Rhinelander, WI) was grown in vitro and used as plant material. Leaf segments were incubated with the liquid bacterial culture with acetosyringone and glucose at various pH in a petri dish for 1 to 2 min and were then wiped several times on a clean dish before being placed on a solid co-cultivation medium (MS basal medium supplemented with 0.2 mg/liter kinetin, 0.5 mg/liter 2,4-D, 20 g/liter sucrose and 0.6% Sigma agar; 10 mM glucose was added when the bacterial culture medium contained glucose; pH was adjusted to 5.8 before autoclaving unless otherwise indicated). Leaf disks mixed with the LB medium without the bacteria were used as controls. After 2 days of co-cultivation at 25°C in darkness, the explants were transferred to a selection medium (the co-cultivation medium plus 60 mg/liter kanamycin, 100 mg/liter carbenicillin and 200 mg/liter cefotaxime). Selection medium pH was adjusted to 5.8 without exception. The antibiotics and the acetosyringone, which was dissolved in DMSO (dimethyl-*d*$_6$-sulfoxide), were filter-sterilized into the completely cooled liquid medium or warm (about 50°C) solid medium after autoclaving at 121°C for 18 min.

Assay for GUS Activity.--Each callus or surviving leaf explant from each petri dish was assayed with X-gluc (5-bromo-4-chloro-3-indolyl-β-glucuronide) in 4 to 6 weeks to determine the frequency of gene transfer. Assay procedures used were according to Jefferson (1987). Small pieces of calli, about 50 mg, or whole leaf disks were mixed and submerged with 100 µl X-gluc and incubated at 37°C for overnight. The fresh leaf (without culturing on the co-cultivation or selection medium) and the control leaf disks were also incubated with X-gluc. The criterion for transformation was development of blue color in the tissue observed under a dissecting microscope. Percentage of calli or explants with blue color or blue spots relative to the total number of inoculated explants was calculated as the transformation frequency.

Experimental, Design and Data Analysis.--Effect of acetosyringone at different concentrations (0, 25, 50, and 75 µM) on gene transfer was first investigated at pH 6.4. Then the optimum range of acetosyringone was adopted to determine possible interactions between acetosyringone and pH at 5.6 and 6.4. Finally, the influence of 10 mM glucose with 25 µM acetosyringone on the transformation efficiency was determined at pH 5.5, 5.8 and 6.1. Cocultivation medium pH was adjusted to the same level as that of the LB medium in this experiment.

Each treatment or control in the present study included three petri dishes; each petri dish containing 13 to 20 leaf explants was considered a replication. Each of the last two experiments was a two-factor factorial design with three replications per treatment combination. Transformed tissue numbers were assumed to follow a binomial distribution. Data from each experiment were analyzed by logit analysis, including single degree of freedom contrasts to separate proportions of transformed tissue, where appropriate.

Results and Discussion

After being cultured on the selection medium for 4 to 6 weeks, some explants formed and integrated into vigorous growing calli while some grew slowly and formed calli only on the surface. Other leaf segments turned brown or pale and died. However, not all of the calli or tissues that survived the selection showed visible GUS gene expression, which was indicated by the dark blue spots after X-gluc staining. Tissue showing at least one blue spot was considered a transformation. Meanwhile, most of the control explants were killed on the selection medium; a few survived but never formed vigorous calli. No gene expression was observed in the fresh leaf tissue, surviving control explants or the bacteria culture.

Without using acetosyringone, the average transformation frequency in the line NC5331 was less than 10% (Huang, 1994). With acetosyringone, the transformation efficiency was significantly increased (Fig. 1). The highest transformation frequency was achieved with the addition of 25 µM acetosyringone. The efficiency gradually declined with the acetosyringone level increased to 75 µM but was still significantly higher than without acetosyringone. Enhanced transformation efficiency has been demonstrated in various plant species with addition of acetosyringone at 20 to 200 µM (Sheikholeslam and Weeks, 1987; Owens and Smigocki, 1988; Godwin et al., 1991; Khan et al., 1994). Up to 200 µM acetosyringone is not considered to be significantly toxic to *Agrobacterium* cells (Stachel et al., 1985). However, growth of certain bacterial strains has been inhibited by acetosyringone, and the growth inhibition was accompanied by the loss of virulence (Fortin et al., 1992). Some evidence also suggests that acetosyringone may suppress virulence in some strain/plant species interactions at a high concentration of acetosyringone (Godwin et al., 1991). Extra high levels of acetosyringone decreased the transformation frequency in soybean (*Glycine gracilis* and *G. max*) (Li and Komatsuda, 1995). In the present study, transformation efficiency showed a decreasing trend with the presence of additional acetosyringone over 25 µM, which suggested that a

bacterial strain and/or a plant species only prefer a narrow range of acetosyringone concentrations.

The efficient transformation with acetosyringone was

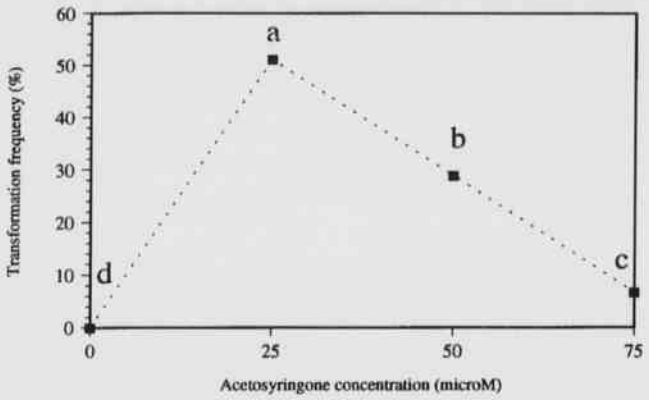

Fig. 1. Acetosyringone effect on *Agrobacterium*-mediated gene transfer efficiency at pH 6.4. abcd - The frequencies not sharing a common letter indicate a statistical difference at $P<0.05$.

also dependent on pH (Fig. 2). Without the addition of acetosyringone, gene transfer frequency was not affected by pH but was very low at both pH 5.6 and 6.4. By contrast, elevating the pH of the LB medium during induction significantly enhanced transformation with the addition of acetosyringone at 30 and 60 µM. In addition, it was demonstrated again that acetosyringone at the higher level (60 µM) decreased the frequency of transformation at pH 6.4 compared to acetosyringone at 30 µM. The acetosyringone-mediated virulence gene induction increased with the decreasing of pH from 6.2 to 5.1 and usually required a pH lower than 5.8 (Stachel et al., 1986; Bolton et al., 1986). Therefore, a low pH (5.2 to 5.8) has usually been used in the induction or co-cultivation medium with addition of acetosyringone in plant transformation (Sheikholeslam and Weeks, 1987; Godwin et al., 1991). However, controversial results have been reported indicating that an efficient transformation in plants has not always been achieved at lower pH with the same amount of signal phenolic compounds and that pH preference was dependent on the plant species or type of phenolic inducer (Godwin et al., 1991; Horford et al., 1992). In addition, Khan et al. (1994) reported that 20 µM acetosyringone enhanced transformation efficiency in *subterranean clover (Trifolium subterraneum* L.) without adjusting the pH of LB medium, which was about 7.0. They also noticed that reducing the pH to 5.8 with or without acetosyringone resulted in a very low gene transfer rate (personal communication with M. Rafiqul Khan, Commonwealth Scientific and Industrial Research Organization, Division of Plant Industry, Canberra, Australia). Li and Komatsuda (1995) reported that ph at 5.8 is optimum for soybean transformation with addition of acetosyringone, but the gene transfer frequency is still high at pH 6.5. Godwin et al. (1991) suggested that pH may be depressed by leakage of cell contents into the micro-environment around explants, and hence, optimum pH would be reached on the less acidic media, but direct evidence is lacking.

In this study, the pH of the co-cultivation medium was

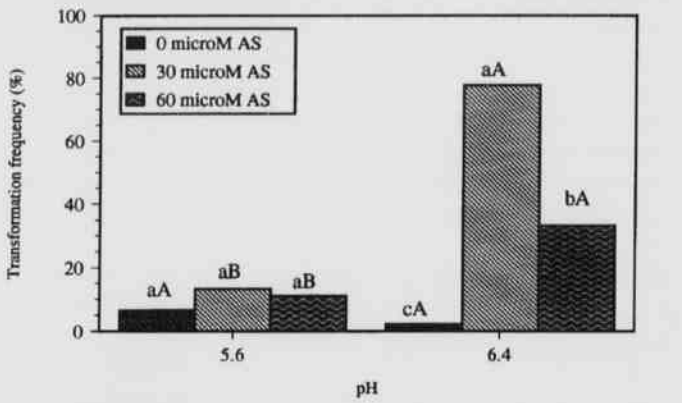

Fig. 2. Effect of pH on the transformation with addition of acetosyringone (AS). abc - The frequencies within the same pH not sharing a common letter in lower case indicate a statistical difference at $P<0.05$. AB - The frequencies within the same acetosyringone concentration not sharing a common letter in upper case indicate a statistical difference at $P<0.05$.

5.8; therefore, pH of the micorenvironment around the explants may be decreased from pH 6.4 due to the contact between the explants and bacterial culture. However, adjusting the pH of co-cultivation medium to the same as the LB medium during the induction did not change the basic trend that transformation frequency at pH 5.5 was much lower than that at pH 5.8 and 6.1 with addition of acetosyringone (data not shown). Therefore, pH adjustment in the LB medium during induction should be more critical than that in the co-cultivation medium. Although results from the studies on *Agrobacterium* suggested that acetosyringone induced the virulence genes at low pH, it is not clear if pH and acetosyringone may affect plant transformation through processes other than inducing expression of virulence genes. For example, studies investigating the binding of *Agrobacterium* to plant cells indicated that optimum pH was 6.0 rather than 5.0 to 5.5 (Ohyama et al., 1979; Neff and Binns, 1985; Porter, 1989).

The effect of glucose and 25 µM acetosyringone at pH 5.5, 5.8 and 6.1 on transformation is shown in Fig. 3. Again, acetosyringone significantly enhanced transformation frequency at a higher pH as compared to lower pH. However, addition of glucose altererd the pattern that acetosyringone promoted transformation only at high pH. Acetosyringone-

stimulated transformation was not affected by pH when 10 mM glucose was added. Acetosyringone and glucose can act synergistically as virulence-inducing agents during infection by *Agrobacterium* (Cangelosi et al., 1990; Shimoda et al., 1990), and hence, gene transfer efficiency could be potentially enhanced. However, such results were mostly achieved at lower pH. The possible interaction between pH and monosaccharides has rarely been studied. In this study, although the increase did not statistically differ, glucose enhanced the transfer efficiency at pH 5.5 while decreasing the efficiency at pH 5.8 (not significantly different) and 6.1 (significantly different). Further evidence is needed to determine how glucose with acetosyringone affects plant transformation at various pH levels.

Bacterial growth rate was slightly higher in the medium

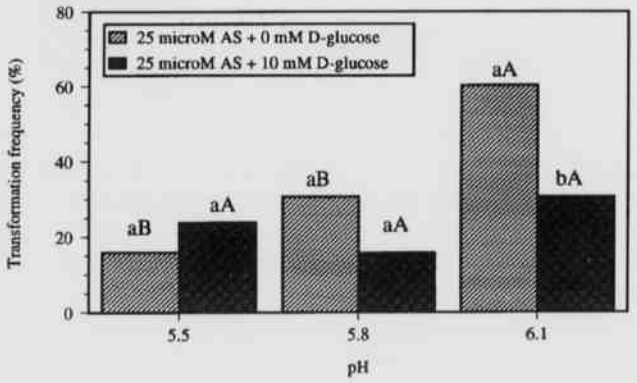

Fig. 3. Effect of acetosyringone (AS), pH and glucose on gene transfer efficiency. ab The frequencies within the same pH not sharing a common letter in lower case indicate a statistical difference at $P<0.05$. AB - The frequencies within the same glucose concentration not sharing a common letter in upper case indicate a statistical difference at $P<0.05$.

at initial pH 6.1 compared to the pH 5.8 or 5.5. For example, after 16 h growth, OD_{600} values of bacterium cultures with 25 µM acetosyringone at initial pH 6.1, 5.8 and 5.5 were 0.56±0.10, 0.53±0.06 and 0.49±0.06, respectively. Bacterial growth resulted in pH increasing significantly within 24 h and then a slight decrease after 48 h in LB medium (Fig. 4). This result indicated that the pH of the microenvironment around the leaf segments might have also been increased because of bacterial growth during the co-cultivation. Although it is not clear at this point if the potential environmental changes, such as pH, affect gene transfer, the microenvironment during co-cultivation may be not stable as we expected. And this may be another important factor to be considered for *Agrobacterium*-mediated transformation. On the other hand, we noticed that fewer pH changes were induced with the addition of glucose (Fig.4).

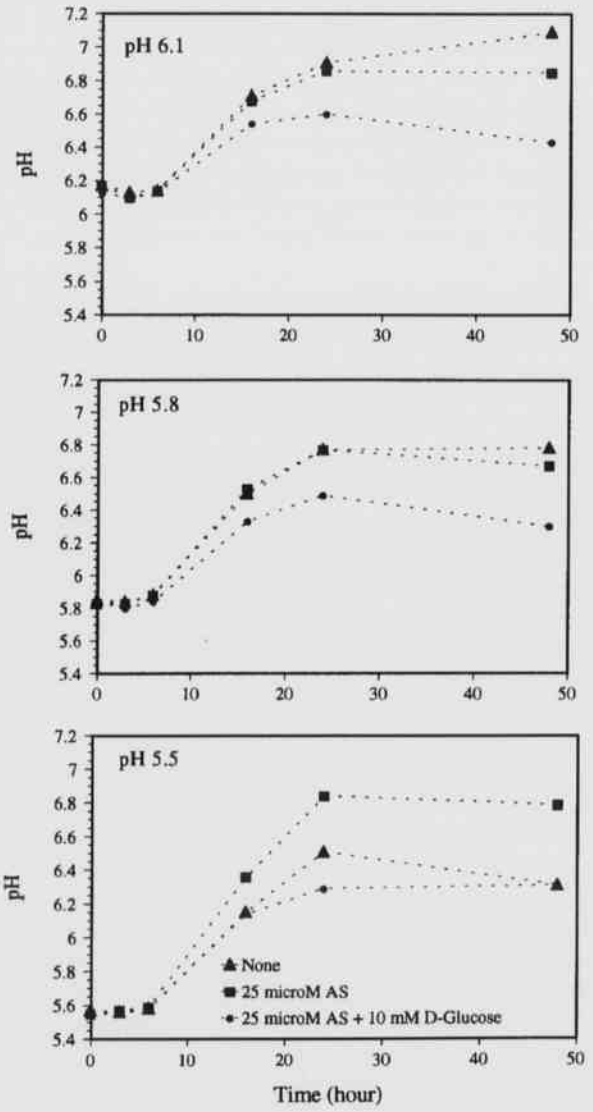

Fig. 4. The pH changes with the *Agrobacterium* growth in LB medium at various conditions. Note - the initial pH was slightly increased after autoclaving and addition of acetosyringone (AS).

Conclusions

Our results indicated that the major factors affecting gene transformation efficiency were acetosyringone and pH. Acetosyringone significantly increased transformation efficiency in poplar hybrid line NC5331, especially at low concentrations (25 to 30 µM). Additional acetosyringone result-

ed in less efficient gene transfer than that at the low concentrations. Even with the addition of acetosyringone, lower pH resulted in lower transformation frequency, and a pH greater than 5.8 was suggested to achieve an efficient gene transformation. Glucose acted antagonistically with acetosyringone to decrease the efficiency of plant transformation at pH 6.1 but did not affect transformation at lower pH. Based on the present study, we conclude that optimizing transformation conditions may be very critical for a specific plant species and/or the *Agrobacterium* strain. The transformation efficiency could be within a wide range of 0 to above 50%.

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Variability in Forest Floor Mass and Nutrient Concentration of Mature Pine-Hardwoods in the Ouachita Mountains

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Abstract

Prior to timber harvesting, forest floor mass and nutrient concentrations in forest floor and mineral soil were determined in 24 mature, shortleaf pine (*Pinus echinata* Mill.)-hardwood stands occurring within the northem, eastern, southern and western sub-ecoregions of the Ouachita Mountains. The forest floor samples were collected at each of three locations representing the lower, mid, and upper slope positions within each stand. Samples of the L-(litter) and F-layers (fermentation) were collected separately. Materials from the L-layer were differentiated into hardwood foliage, pine foliage, and woody/reproductive components. Mass and nutrient concentrations of the various forest floor components were compared among slope positions and among sub-ecoregions to evaluate the influence of these factors on forest floor pools. Forest floor mass and nutrient concentrations generally did not differ among slope positions. Although mass did not differ among sub-ecoregions, forest floor concentrations of Ca, Mg, and Mn were significantly higher in the northern than the eastern or southern portion of the Ouachita Mountains.

Introduction

The forest floor consists of organic matter on mineral soil surface which accumulates from forest aboveground biomass This organic material is an important source of mineralizable nutrients/carbon and is an essential component of forest ecosystem energy/nutrient cycles. Spatial variation of forest floor characteristics within forest stands or among stands across the landscape can generally be related to the variation in abiotic or biotic factors. Soil parent material and climate are two abiotic factors which have been found to affect forest floor characteristics and are known to vary among slope positions and sub-ecoregions in the Ouachita Mountains (Graney, 1992; Baker, 1994). As part of a project addressing the effects of diversified harvesting and silvicultural treatments on various commodity and noncommodity resources in shortleaf pine (*Pinus enchinata* Mill.) hardwood stands, we quantified the amount and chemistry of forest floor within 24 shortleaf pine-hardwood stands prior to harvesting in the Ouachita/Ozark National Forests. This information was used to determine if these forest floor characteristics differed among slope positions and sub-ecoregions in the Ouachita Mountains.

Materials and Methods

Study Area and Sampling Design.--Twenty four relatively undisturbed, mature, shortleaf pine hardwood stands occurring in the Ouachita Mountains of Arkansas and Oklahoma were included in this study. Only stands with the following attributes were considered for inclusion in the study: 1) average tree age >70 years, 2) stand area >14 ha, 3) stands on southern facing slopes, 4) pine basal area between 13.8 and 25.2 m^2 ha^{-1}, and 5) hardwood basal area between 4.6 and 11.5 m^2 ha^{-1}. From this general population of stands, six were randomly selected from within each of four sub-ecoregions representing the northern, western, eastern and southern portions of the Ouachita Mountains. These sub-ecoregions represent the general variation in land forms, soil, geology, and climate within this area (Clingenpeel and Cochran, 1992; Baker, 1994).

Each stand was subdivided into quarters to facilitate establishing 12 randomly located, permanent subplots that were used for sampling vegetation by other project components. These quarters were oriented perpendicular to the dominant slope within the stand. From a randomly chosen quarter within each stand the subplot representing the lower, middle, or upper portion of the slope was chosen for forest floor sampling (Shelton and Lawson 1994). In total, 72 subplots were sampled in the 24 stands.

Field Sampling.--Sampling was conducted during February and March of 1993. Five sampling locations were systematically located 11.4 m from each subplot center. Sampling locations were relocated if abnormal conditions such as large surface rocks, woody debris more than 7.5 cm in diameter, or previous manmade disturbance (e.g., old roads, etc.) occurred at the sampling location. Thus samples and results reflect potential optimal forest floor conditions from undisturbed areas which are not dominated by rocks

or woody materials rather than an average surface conditions in the stands as a whole. Approximately less than 5% of the sample locations had to be relocated due to these criteria. The forest floor was collected from within a 0.1-m^2 square frame at each sampling location. Two forest floor layers representing two stages of decomposition were collected. The first was a litter (L) layer, which included the uppermost, current year undecomposed plant material and the other a fermentation (F) layer consisting of partially decomposed/fragmented older material located above the mineral soil surface and below the L layer. The L and F layers are also commonly referred to as Oi and Oe horizons, respectively (Pritchett 1987). The humus layer, a thin layer of amorphous organic matter (Oa horizon) lying on top of the rnineral soil, was not collected nor included with the F layer.

Laboratory Procedures.--Forest floor samples were dried at 75° C until a constant moisture content was obtained and then mass determined. Each L-layer sample was separated into woody and foliar components. The woody component included branches, bark, small stems, and reproductive material (e.g., pine cones). The foliar component of the samples for each subplot was separated into pine and hardwood foliage and weighed. Thus, the L-layer was represented by pine foliage, hardwood foliage, and woody components. All mass were expressed as totals and not corrected for loss on ignition as reported by Shelton and Lawson (1994).

Forest floor components were composited for a subplot and mass was determined. Then samples were ground to pass a 20-mesh sieve. Concentrations of P, K, Ca, Mg, Mn, Na, Cu, Fe, and Zn were determined by inductance coupled plasma (ICP) analysis after nitric/perchloric digestion (University of Arkansas, Soil Test Laboratory, 1990a). Total N concentrations were also determined using a Tecator Kjeltec Model 1030 Auto Analyzer after sulfuric acid/hydrogen peroxide digestion (University of Arkansas, Soil Test Laboratory, 1990b).

Data Analysis.--Forest floor data were analyzed using analysis of variance for a two factorial design. Sub-ecoregion and topographic position were the two factors. Mean separation was accomplished using Tukey's Honestly Significant Difference multiple-range test (Steel and Torrie 1980) at the α=0.05 after analysis of variance tests indicated differences in a factor were significant.

Results And Discussion

Slope.--Comparison of forest floor nutrient concentrations and mass showed generally no significant or consistent differences among slope positions. Total L-layer (Table 1) macronutrient concentrations were very similar among the lower, mid, and upper positions. Concentrations for some micronutrients were higher in the lower slopes while concentrations of others such as Cu or Zn were higher in the upper slopes. Regardless of the nutrient considered, differences among slope positions for any component in the L-layer were not significant.

Table 1. Forest floor total L-layer nutrient concentrations and mass by slope position.

	Lower	Mid	Upper
	%		
N	0.69	0.69	0.67
P	0.05	0.05	0.05
K	0.07	0.07	0.07
Ca	1.09	1.02	0.96
Mg	0.12	0.11	0.11
	mg kg^{-1}		
Cu	10	12	15
Fe	326	229	227
Mn	1156	1056	968
Na	225	238	236
Zn	100	129	133
	10^3 kg ha^{-1}		
Mass	5.6	5.1	5.5

Nutrient concentration and mass of the F-layer were also similar among slope positions. Only Zn had significantly different concentrations among the slope positions. Mean concentrations of Zn in the mid-slope position was (89 mg kg^{-1}) and was significantly greater than concentrations in the upper slope position (89 mg kg^{-1}). The general lack of differences in forest floor chemistry and mass among slope positions can be attributed to the high variation in slopes among stands and the methodology used to delineate slope position within a stand. Average slopes for the subplots ranged from 2 to 44% in the stands. Differences in forest floor concentrations or mass would likely be greater within stands which had greater slopes than stands with less slope. A number of stands occurred on landforms with minimal slopes and thus differences in forest floor among slope positions were minor as well.

Slope position of a subplot was delineated relative to the position of the subplot in the stand rather than its position along a landform. Designation of a subplot's slope position using the general landform rather than its location within the stand indicated that entire stands could occupy only one slope position. Given this lack of difference among slope positions, it was not surprising that differences in forest floor among subplots were inconsequential.

Sub-Ecoregion.--Variability in nutrient concentrations among sub-ecoregions was greater than the variability among slope positions. Concentrations of Ca and Mg in the L-layer and Ca in the F-layer were consistently lower in the east region than in the north (Table 2) while Mn concentrations for all forest floor components were significantly lower in the southern region than the north (Table 3). Concentrations of Ca and Mg were 18-42% higher in the northern compared to eastern sub-ecoregion while concentrations of Mn was 30-33% higher in the northern compared to southern sub-ecoregion. All other nutrients, except Cu in the F-layer, did not significantly differ among sub-ecoregions.

Table 2. Macronutrient concentrations and mass of pine and hardwood (Hwd) foliage in the L-layer and in the F-layer (F) by sub-ecoregions.

		North	East	South	West
		%			
N	Pine	0.64a	0.68a	0.65a	0.66a
	Hwd	0.91a	0.90a	0.91a	0.94a
	F	0.94a	0.99a	1.02a	0.95a
P	Pine	0.05a	0.05a	0.05a	0.05a
	Hwd	0.06a	0.05a	0.05a	0.07a
	F	0.06a	0.06a	0.06a	0.06a
K	Pine	0.08a	0.07a	0.08a	0.07a
	Hwd	0.09a	0.08a	0.09a	0.10a
	F	0.11a	0.10a	0.09a	0.09a
Ca	Pine	0.66a	0.53b	0.62a	0.60ab
	Hwd	1.66a	1.30b	1.49ab	1.66a
	F	0.87a	0.62b	0.76ab	0.76ab
Mg	Pine	0.13a	0.11b	0.12ab	0.11b
	Hwd	0.20a	0.14b	0.17ab	0.17ab
	F	0.11a	0.11a	0.09a	0.10a
		10^3 kg ha^{-1}			
Mass	Pine	1.72a	1.73a	1.73a	2.02a
	Hwd	1.68a	1.54a	1.77a	1.68a
	F	20.91a	19.63a	18.85a	19.59a

[1]Concentrations or mass for a given component with same letters are not significantly different at α=0.05

Differences in Ca, Mg, and Mn among sub-ecoregions did not appear to be related to aboveground production of litter because neither mass of L or F-layers significantly differed among sub-ecoregions. Although it is well documented that increased inputs, cycling, and/or soil availability of Ca and Mg occur with an increased level of hardwoods in a stand (Pritchett, 1987; Binkley and Valentine, 1991), there was no evidence that differences in nutrient concentrations among sub-ecoregions were related to stand composition. Statistical comparisons demonstrated that neither stand hardwood nor pine basal area differed among sub-ecoregions.

Table 3. Macronutrient concentrations in pine and hardwood (Hwd) foliage in the L-layer and in the F-layer (F).

		North	East	South	West
		mg kg^{-1}			
Cu	Pine	12a	19a	21a	12a
	Hwd	7a	9a	17a	24a
	F	11ab	10b	12a	11ab
Fe	Pine	136a	170a	177a	169a
	Hwd	273a	237a	255a	498a
	F	6610a	5793a	4313a	4853a
Mn	Pine	1078a	914ab	828b	865b
	Hwd	2121a	1730ab	1593b	1920ab
	F	1803a	947b	1074b	1281b
Na	Pine	133a	179a	187a	137a
	Hwd	104a	69a	132a	196a
	F	723a	776a	725a	766a
Zn	Pine	188a	160a	157a	143a
	Hwd	107a	90a	73a	130a
	F	87a	77a	67a	86a

[1]Concentrations for a given component with same letters are not significantly different at α=0.05

Although stand composition and production appear to be similar among the sub-ecoregions, these regions do differ in their climate and geology. Mean annual precipitation is 10-20 cm less in the northern sub-ecoregion than in the other sub-ecoregions (Skiles 1981). Stratigraphy and lithology are two of the most relevant factors used to delineate these sub-ecoregions into separate subsections in the classification system created by Keys et al. (1995). The stratigraphy and lithology of these four subsections are described in the following manner: the northern subsection has (Fourche Mountains) sandstone and shale-clast loamy colluvium, the east (East Central Ouachita Mountains) subsection a chert fragment and quartzite boulder colluvium, the south subsection (Athens Piemont Plateau) has acid chip clay-loam and bouldery sandy colluvium, and the west subsection (West Central Ouachita Mountains) has acid shale-chip and clay loam colluvium. These differences in geology and climate apparently have influenced the soils within these sub-ecoregions and thus the chemistry of the forest floor. It is interesting to note that although similar species compositions exist within stands, differences in soils attributed to what is assumed to be relatively small differences in climate or geology, have altered the chemistry of the forest floor with sig-

nificant enough magnitude to be detected at a moderate sampling intensity.

Conclusions

Variation in forest floor micro- and macronutrient concentrations in shortleaf pine-hardwood stands was found to be greater among stands occurring in different sub-ecoregions than among slope positions within stands. The lack of any substantial differences in concentrations among slope positions was in part attributed to the methods used to delineate slope position. The criteria utilized for stand and plot selection in this study was not suited for the testing of landform level differences in slope position. Variation in climate and geology appeared to be two of the more important factors contributing to the differences in forest floor nutrient concentrations among subecoregions.

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A Method to Correct the Voxel Size in PRESS Localized NMR Spectroscopy

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Abstract

Two techniques commonly used on human magnetic resonance spectroscopy systems to obtain spectra from localized volumes in the brain are point resolved spectroscopy (PRESS) and stimulated echo acquisition mode (STEAM) spectroscopy. PRESS gives a signal twice as large as that obtained with STEAM, but suffers from longer minimum echo times. While STEAM must be used to detect species with short spin-spin relaxation times, PRESS can be used for species with longer relaxation times to give a spectrum with a better signal to noise ratio. Only STEAM was provided for the GE Omega 4.7 T small animal imager used in this laboratory. Therefore, a PRESS pulse program was written for this instrument. With the standard sequence, the sampled voxel is smaller than the prescribed voxel. A larger voxel can be prescribed to increase the sampled volume. A different approach, involving the modification of the gradient strength, has been used in this laboratory. The resulting pulse sequence, with representative profiles, is discussed.

Introduction

A phosphorus-31 spectrum of muscle introduced *in vivo* nuclear magnetic resonance (NMR) spectroscopy in 1980 (Cady, 1990). An *in vivo* spectrum from rat brain followed in 1983. By 1986, several techniques for obtaining *in vivo* spectra had been developed [Bottomley, 1986]. Two popular techniques for obtaining *in vivo* proton NMR spectra are point resolved spectroscopy (PRESS), which was introduced in 1984 (Bottomley, 1984; Ordidge, et. al., 1985), and a similar technique, stimulated acquisition mode (STEAM) spectroscopy, which was described in a 1987 publication (Frahm, et. al., 1987). Both of these techniques are used with commercial magnetic resonance imagers. They are not as routinely used with small animal imagers.

Theory

Nuclei precess in a magnetic field at the Larmor frequency, which depends on the magnetic field strength:

$$\omega_0 = -\gamma B_0, \qquad (1)$$

where ω_0 is the frequency, γ is the magnetogyric ratio, and B_0 is the magnetic field strength. The magnetogyric ratio for a given nucleus must be determined experimentally.

In the field, a small excess of the nuclei align themselves so that the z components of their magnetic vectors are coaxial with the field. The system has a net magnetic moment, **M**, which is aligned with the external $\mathbf{B_0}$ field, as shown in Fig. 1.

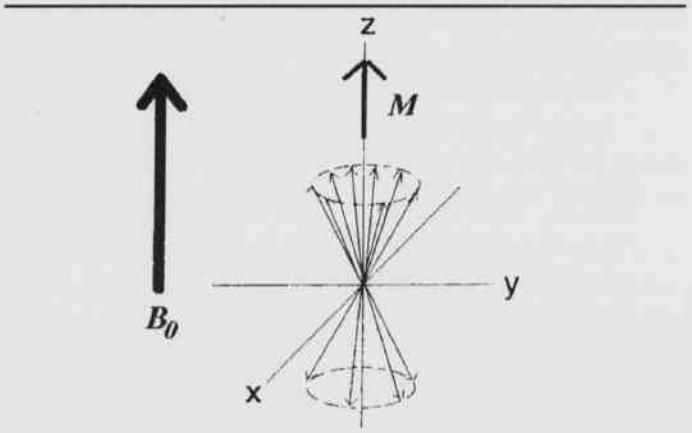

Fig. 1. In an ensemble of spins, a small majority is in the lower energy state. This results in a net magnetic moment, **M**, aligned with the main magnetic field, $\mathbf{B_0}$.

If an additional field, $\mathbf{B_1}$, is introduced into the system, a new effective field, $\mathbf{B_{eff}}$, is generated. At equilibrium, the net magnetic moment will align itself with $\mathbf{B_{eff}}$ and the individual nuclei will precess at a frequency given by

$$\omega = -\gamma B_{eff}, \qquad (2)$$

where B_{eff} is the magnitude of $\mathbf{B_{eff}}$.

Let B_1 oscillate at the Larmor frequency, ω_0, and introduce new coordinate axes which rotate at the same frequency. The new axes are denoted x', y', and z' and are related to the stationary axes as follows: the z and z' axes are coincident, while x' and y' rotate about z. In this rotating frame of reference, $\mathbf{B_1}$ appears stationary and the $\mathbf{B_0}$ field disappears (Farrar and Becker, 1971). In the rotating frame, the net magnetic moment rotates about the $\mathbf{B_1}$ field.

For example, let $\mathbf{B_0}$ be oriented along the z-axis and let $\mathbf{B_1}$ coincide with the x-axis. In the rotating frame, **M** will experience a torque from the $\mathbf{B_1}$ field and rotate onto the negative y axis, as shown in Fig. 2.

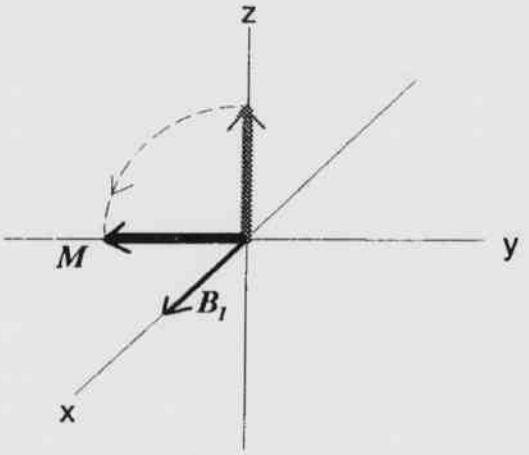

Fig. 2. A $\mathbf{B_1}$ field oscillating at the Larmor frequency is applied along the x-axis. **M** rotates around the x-axis as long as the $\mathbf{B_1}$ field is applied. Here, **M** has rotated 90°.

In the rotating frame, the angle through which the magnetization rotates is given by

$$\theta=\omega t=\gamma B_1 t \qquad (3)$$

where t is the length of time the field is present and B_1 is its magnitude. A pulse of radio frequency (RF) energy at the Larmor frequency provides the $\mathbf{B_1}$ field. If the pulse is long enough to rotate **M** by 90°, it is called a 90° pulse. Any desired flip angle can be generated by varying the time for which the RF energy is applied.

After **M** has been tipped into the xy plane and the $\mathbf{B_1}$ field is removed, the spins return to their original alignment along the z axis. This process is called relaxation. There are two time constants associated with relaxation: the spin-lattice relaxation time, T_1, and the spin-spin relaxation time, T_2. The spin-lattice relaxation time is a measure of how long it takes for magnetization along the z axis to recover; the spin-spin relaxation time is a measure of how long magnetization persists in the xy plane. In general, T_1 refers to exponential growth and T_2 refers to exponential decay of the relevant magnetization.

A potential problem with NMR is that the pulse excites a range of frequencies. Theory shows that the bandwidth of a simple on-off pulse is approximately equal to the inverse of the pulse length (Farrar and Becker, 1971). If the pulse length is very short, the bandwidth is broad and spins with largely differing Larmor frequencies are excited. If the pulse is very long, spins with only a narrow distribution of Larmor frequencies will be excited. In *in vivo* spectroscopy, the distribution of frequencies is used to achieve spatial localization.

The frequency response of a pulse is approximated by the Fourier transform of its shape in the time domain. The Fourier transform of a rectangular pulse is a sinc function centered at the RF frequency of the pulse. Other frequencies, contained in the middle and side lobes of the response, are also excited. For many purposes, such a broad excitation is undesirable. To excite a plane of spins, for example, the frequency response should be a well-defined rectangular function.

One of many approaches to defining the frequency response is to Fourier transform the desired response. The resulting function is then used to modulate the RF pulse. Since the transform of a rectangular function is a sinc function, a sinc shaped RF pulse gives a more nearly rectangular excitation.

When shaped RF pulses are used, the flip angle is adjusted by changing the power of the pulse. This corresponds to altering the amplitude of the $\mathbf{B_1}$ field. A 90° power level, rather than a 90° pulse width, is defined.

Localization

Localized NMR experiments must include some means of identifying the position from which the signal originates. Gradients are used in conjunction with the RF pulse to localize the signal.

A gradient is a linearly varying magnetic field that is applied in addition to the $\mathbf{B_1}$ and $\mathbf{B_0}$ fields. Let the strength of this gradient be represented as kx, for a gradient along the x axis of magnitude k. The effective field strength is given by

$$B_{eff}=B_0 + B_1 + kx. \qquad (4)$$

Since $\omega=-\gamma B_{eff}$, the Larmor frequency now is proportional to kx. Spins at different x locations will have different Larmor frequencies. Only those spins with Larmor frequencies in the bandwidth of the RF pulse will be affected. Since frequency now depends on position, bandwidth now corresponds to a range of x values.

Consider a gradient for which k is 1 gauss/cm (G/cm), as shown in Fig. 3. Let γ for the nucleus of interest be 4

kHz/G and suppose a 1 ms hard pulse is applied. The bandwidth is then 1/1 ms or 1 kHz. Spins with frequencies ± 1 kHz from the center frequency will be excited. The gradient corresponds to a frequency change of 4 kHz/cm, so the pulse excites a 0.5 cm length of spins along *x*. Since the object to be imaged is three dimensional, a 0.5 cm thick plane of spins perpendicular to the x-axis has been selected.

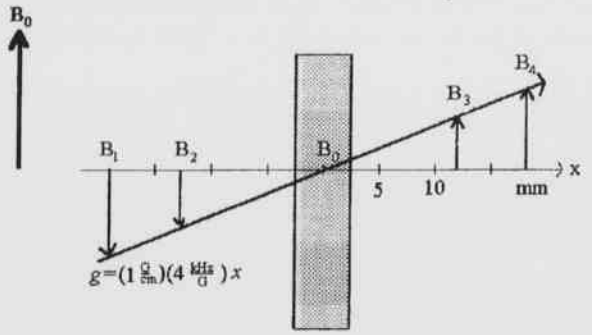

Fig. 3. A 1 ms pulse in the presence of a 1 G/cm x gradient is applied to a system with a magnetogyric ratio of 4 kHz/G. Since the slope of the gradient is 4 kHz/cm, the +1 kHz of excited frequencies centered about $\omega_0 = -\gamma B_0$ is mapped into a slab of spins 0.5 cm thick. The shading represents the area of excited spins.

If a gradient subsequently is applied in the y direction, with a concurrent RF pulse, two planes of spins will be excited. Only along the intersection of those planes will the spins have experienced both pulses. Applying a third gradient along z, with a simultaneous RF pulse, will selectively excite the intersection of three planes. Figure 4 illustrates this intersection, or voxel.

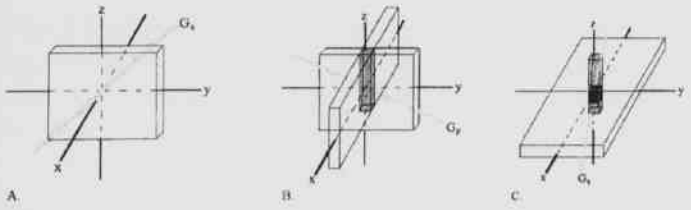

Fig. 4. A. Use of only the x gradient to select a slab of spins. B. Addition of the y gradient selects a column of spins, as indicated by the shaded region. C. Addition of the z gradient selects a box, as shown by the black region in the center. The x and y planes have been omitted for clarity. In all cases, the direction of the gradient is indicated by the dotted line.

The signal collected after the final RF pulse can be Fourier transformed to give a spectrum from the excited voxel. However, spins outside the voxel may contribute to the magnetization in the xy plane at the end of the experiment. Additional gradient pulses are needed to isolate the voxel.

Any sequence that uses multiple RF pulses generates a series of echoes. Hahn showed that, for a sequence of three pulses, a total of five echoes may be generated (Hahn, 1950). Two sequences that utilize these echoes are stimulated echo acquisition mode (STEAM) spectroscopy and point resolved spectroscopy (PRESS).

STEAM uses three 90° pulses to localize the voxel and, therefore, acquires a stimulated echo (Hahn, 1950). PRESS uses a 90° pulse followed by two 180° pulses and acquires a spin echo. The stimulated echo is only half as large as a spin echo acquired from the same region [Hahn, 1950], but the STEAM sequence is preferable for collecting spectra from species with short T_2's. PRESS, however, is the preferred sequence if some T_2 relaxation is permissible in the experiment.

Point Resolved Spectroscopy

Point resolved spectroscopy uses three RF pulses and three gradients to choose a voxel. Figure 5 is a timing diagram for the sequence. The length of time between the first two pulses determines the echo time (TE), which is the interval between the center of the first RF pulse and the start of data acquisition.

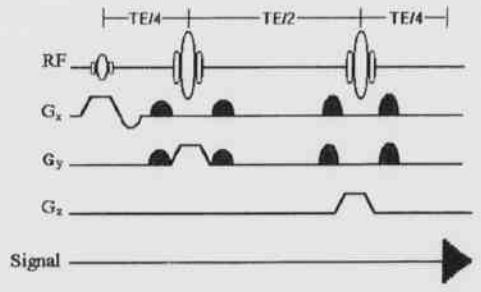

Fig. 5. The PRESS timing diagram.

The first RF pulse is a sinc shaped 90° pulse, which is applied with an x gradient. This causes the spins within a plane perpendicular to the x axis to rotate onto the negative y axis. During TE/4, the interval between the first two pulses, the spins dephase by an amount $(\Delta\omega)(TE/4)$, where $\Delta\omega$ is the frequency difference between the frequency of the RF

pulse and the precessional frequency of a given spin. A 180° pulse, with its associated y gradient, is then applied and flips the spins 180° about the y axis, without changing the direction in which they rotate. The phase of the spins continues to change, but since the spins that were ahead of ω_0 are now behind ω_0, as seen in Fig. 6, the spins will rephase and form a spin echo TE/4 after the pulse.

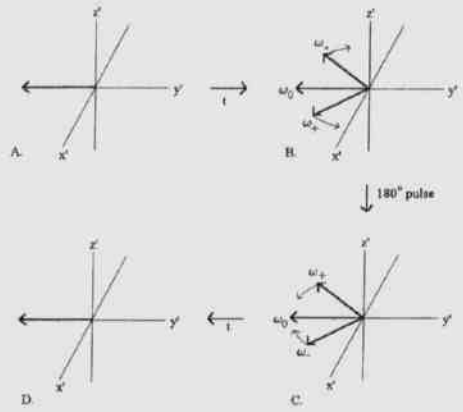

Fig. 6. All diagrams use the rotating frame. A. The spins are in phase in the transverse plane after the 90° pulse. B. The spins have dephased during time *t*. The center frequency, ω_0, appears stationary, while other spins rotate at the frequencies $\omega+$ and $\omega-$. The differing frequencies cause the spins to spread out in the transverse plane. C. After the 180° pulse is applied along the y' axis, the spins exchange places. D. The spins rephase after a further delay, *t*.

Finally, the third 180° pulse is applied TE/2 after the second pulse, which allows the spins to dephase after forming the echo. This pulse again reverses the spins, but only in the voxel, since there is a simultaneous gradient in the z direction. The rephased spins form a spin echo TE/4 after the last pulse.

Although the entire echo can be sampled, in practice, only the second half of the echo is acquired. The primary reason for this delay is the potential for distortion of the echo due to eddy currents from the switched gradients. The second half of the echo, since it occurs later in time, is less likely to be so distorted. Fourier transformation of the sampled data yields the spectrum.

There are several problems with this sequence, most of which arise from imperfect RF pulses. Ideally, each of the 180° pulses causes the transverse spins in the intersection to rephase while simply inverting longitudinal magnetization. However, some of the longitudinal magnetization actually is rotated into the transverse plane (Jung, 1996). This unwanted magnetization contributes to the final signal and must be eliminated.

"Crusher" gradients are used to destroy the unwanted transverse magnetization. If a gradient is applied after a pulse, it dephases the spins in the transverse plane. Crusher gradients are applied after each 180° pulse to dephase the unwanted xy magnetization. However, these gradients also destroy the signal from the voxel. To preserve that signal, an equal but opposite gradient must be applied, but only to the spins in the voxel.

Let C2 be the gradient immediately after the 180° pulse and let its slope be *k*. In the rotating frame, this gradient causes spins in the transverse plane to dephase by

$$\Delta\theta = 2\pi\gamma kxt, \tag{5}$$

where *x* is the coordinate of the spin, *t* is the duration of C2, and $\Delta\theta$ is the phase difference with respect to $x = 0$.

If a gradient identical to C2 is applied immediately prior to the 180° pulse, the transverse magnetization will dephase by $\Delta\theta$. The spins in the voxel change places after the 180° pulse and will rephase when C2 is applied, while any new transverse magnetization is dephased. This is identical to Fig. 6, except that now a gradient is used to dephase and rephase the spins, rather than a delay time, *t*. Therefore, to preserve the spin echo, the crusher gradients must be applied symmetrically around the 180° pulse.

The equations which describe the effects of an RF pulse are nonlinear and, for large tip angles, the simple inverse relationship between bandwidth and pulse duration is no longer applicable (Ernst, et. al., 1987; Yan, et. al., 1987; Yan and Gore, 1987a; Yan and Gore, 1987b). The nonlinearity of the response causes a smaller frequency range to be excited for the 180° pulse than for the 90° pulse (Yan, et. al., 1987; Yan and Gore, 1987a; Yan and Gore, 1987b), which results in narrower planes of excited spins. This is shown in Fig. 7. The profiles were obtained using the standard PRESS sequence and correspond to the width of the plane selected by each pulse.

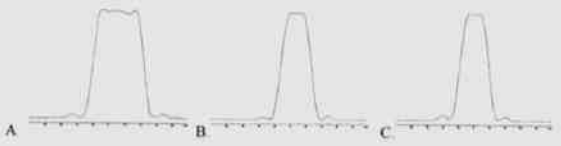

Fig. 7. Profiles obtained using the unmodified PRESS sequence. A. Profile in the x direction using a 90° pulse. B. Profile in the y direction from a 180° pulse. C. Profile in the z direction.

There are three ways to correct the voxel size: prescribe a larger voxel than is actually desired, increase the bandwidth of the 180° pulses, or reduce the gradient strengths which are applied with those pulses (Jung, 1996; Moonen, et. al., 1989). While prescribing a larger voxel is the simplest solution, it requires the operator to make an accurate estimate of the necessary increase in size. Increasing the bandwidth is undesirable because it makes programming and optimizing the sequence timing difficult. For example, increasing the pulse length or number of lobes in the 180° sinc pulse would increase the bandwidth, but then the power for the pulse would not be related easily to the power for the 90° pulse. By keeping the two pulse shapes identical, the power level for the 180° pulse is just twice that of the 90° pulse. The third alternative is the best solution because the reduction in gradient strength is constant for a given system.

For our system, a GE Omega CSI 4.7 T instrument controlled by a Sun 3/160 workstation, the gradients applied with the 180° pulses need to be reduced by 30% to achieve the correct voxel size at half maximum. This reduction is achieved by multiplying the calculated gradient strength by a scaling factor of 0.7.

The apparent gradient strength, using the Fourier transform approximation, is given by

$$G_{app} = sincl/(sinct * st) \quad (6)$$

where G_{app} is the apparent gradient strength, *sincl* is the number of lobes in the sinc pulse, *sinct* is the length of time for which the pulse is applied, and *st* is the desired slice thickness. The actual gradient strength used is given by

$$G_{act} = sf * G_{app} \quad (7)$$

where *sf* is the scaling factor.

Profiles obtained from the PRESS sequence using the default scaling factor of 0.7 are shown in Fig. 8. Empirical measurements with this system have shown that a scaling factor of 0.7 gives the desired voxel size. A scaling factor of 0.775 was required for a similar instrument (Moonen et. al., 1989). Since the scaling factor is constant, it can be evaluated once and programmed into the sequence. Such a default correction allows the operator to prescribe a voxel without having yet another parameter to adjust.

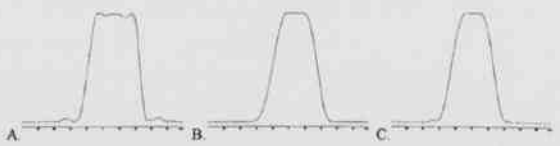

Fig. 8. Profiles from the modified PRESS sequence. A. Profile from the 90° pulse. B. Profile from the first 180° pulse. C. Profile from the second 180° pulse.

The profiles of the 180° planes are not perfectly rectangular. This can be improved by adjusting either the shape of the gradient pulse (Yan and Gore, 1987a), by using multiple RF pulses (Yan and Gore, 1987b), or by using special shaped pulses (Shinnar et. al., 1989a; Shinnar et. al. 1989b). These solutions require either an increase in the complexity of the program or an increase in the duration of the pulse sequence. For some purposes, such increases may be necessary. When they are not, a scaling factor provides a simple means of improving the voxel size.

Conclusion

The PRESS pulse sequence is a good alternative to STEAM for localized *in vivo* NMR spectroscopy. However, it uses 180° pulses, which, due to the nonlinearity of the system, cause unwanted magnetization to contribute to the signal from a voxel that is too small. Careful optimization of the crusher gradients and the slice selection gradients used with these pulses is required. The improper adjustment of the crusher gradients will result in the spin echo being contaminated with signal from outside the voxel. If the slice selection gradients are not adjusted, the sampled voxel will be smaller than desired. Although several methods have been proposed to adjust the voxel size, the simplest method is to multiply the calculated gradient strength by a scaling factor. This scaling factor is constant for a given system, so it can be determined once and incorporated into the pulse program. The operator has one less parameter to adjust, and the program is still easy to implement. The scaling factor is a simple way to make the pulse program both user friendly and accurate.

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Prediction of Potential Antimigraine Activity Using Artificial Neural Networks

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Abstract

More than 10 million Americans, three quarters of them women, suffer some degree of recurrent migraine headaches. Feverfew (*Tanacetum parthenium* (L.) Schultz-Bip.) is a member of the Asteraceae family that is native to Europe. This plant is a perennial flowering aromatic plant common in gardens. It has been widely used as a self-medication of arthritis, fever, and migraine headaches for over 2000 years. Sesquiterpene lactones (SL) are the components responsible for the antimigraine activity of feverfew. In this research, the relationship between SL structural information and their biological activity was studied by using Gaussian 92 program in conjunction with artificial neural networks (ANNs). The molecular orbital parameters of SL were obtained by using Gaussian 92 program. A set of 39 SL molecules was divided into two groups, a training set containing 33 molecules and a testing set containing six molecules. An ANN was trained and tested by using training sets and testing sets on SL's antimigraine activities. The results showed that ANNs successfully predicted the antimigraine activities of SL based on their different structural information.

Introduction

Migraine headaches are highly prevalent disorders, they can be physically and psychologically disabling. More than ten million Americans, three quarters of them women, suffer some degree of recurrent migraine headaches. Migraine can affect any age group but the peak years are ages between 25 and 55. The annual cost of medical care and lost productivity because of migraines in the United States has been estimated to range from $1.2 billion to $17.2 billion (Lipton et al., 1993). It really has become an economic burden on society. Furthermore, reports of migraine in the United States have increased dramatically since 1980, for example, migraines prevalence increased 60% from 1981 to 1989 (Lipton et al., 1997).

Serotonin (5-hydroxytrypamine or 5-HT) is considered to be one of the most important neurotransmitters associated with migraine headaches since recent studies showed that the distribution of 5-HT in the blood of migraine patients differs from that in control subjects. Release of 5-HT from blood platelets can constrict blood vessels and contribute to migraine pain. The antimigraine activity of SL was expressed by the inhibition of serotonin released from platelets by the SL (Marles et al., 1995).

Biological activity of any compound is a direct consequence of its molecular structure, investigations of the relationship between chemical structure and the activity of compound are helpful in understanding the activity of interest and in predicting the activity of new compounds based on knowledge of the chemical structure alone.

This paper discusses one approach which employs self-consistent field-molecular orbital (SCF-MO) quantum mechanical calculations (Clark, 1985) in conjunction with artificial neural networks on prediction of antimigraine activity of SL. The structural information of SL were obtained by using Gaussian 92 program and ANN was trained and tested on the antimigraine activities of 39 SL.

Materials and Methods

Computational studies were performed using Silicon Graphic's R4400 or R4600 computers. There are three main steps used in this research. First, SL structures were obtained directly from Cambridge Structural Database (Cambridge Crystallographic Data Centre, Cambridge, UK) or built by modification of related structures available in this database using some tools in SYBYL 6.2 (Tripos associates, St. Louis, MO, USA). The geometry of lowest energies of each molecule was obtained for the further investigation.

Second, quantum mechanical calculations using the Gaussian 92 program were run on each SL structure to

obtain their structural information, such as eigenenergy and dipole moment. The input for the calculations was an internal coordinate matrix (Z-matrix) of the SL structure with lowest energy. The basis set used was a STO-3G* and POP=REGULAR was used as a keyword to do the regular population analysis. The eigenenergies of the lowest fifteen unoccupied molecular orbitals, the highest fifteen occupied molecular orbitals and the dipole moment of each molecule were chosen from the output file of Gaussian 92.

Finally, ANNs were employed to make the necessary correlation between structual information and the antimigraine activity of SL. The antimigraine activity data of SL were measured as their ability to inhibit the release of serotonin (IC_{50}) and previously reported by Marles and co-workers (1995). IC_{50} is the micromolar concentration of SL that will inhibit the release of serotonin by 50%.

ANNs are computer models that were first developed based on the neural structure of the brain. The brain basically learns from experience. In particular, the most basic element of the human brain is a specific type of cell known as neurons. The power of the human mind comes from the large numbers of these basic components and the multiple connections between them. ANNs are massively parallel computing systems made up of a number of simple, highly interconnected processing elements which process information by determining the value of an output signal based on the values of several input signals. Figure 1 shows a three layer fully connected ANN.

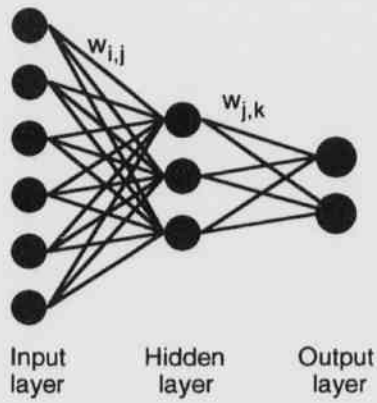

Fig. 1. Architecture of a three layer Artificial Neural Network.

ANN used in this research is error back propagated supervised neural network. It was first developed by McClelland and Rumelhart (McClelland and Rumelhart, 1986). It has been successfully used in our previous studies (Darsey, et.al, 1993; Soman, et al, 1995). As shown in Fig. 1, it has three layers inside of the network: input layer, hidden layer and output layer. Each layer usually includes several processing elements (or neurons, nodes, etc) which are the basic element of neural network. The nodes of the input layer are responsible for the distribution of the input to the next layer of nodes. One hidden layer is placed between the input and output layers.

In this case, 31 nodes which included 30 eigenenergies and 1 dipole moment, were placed in input layer, 12 nodes were used in hidden layer and only 1 node was used in output layer which was antimigraine activity of SL. All these nodes were interconnected through unidirectional connection (weights). Weights are adaptive coefficients that are changed when the network learns. Randomly set weights are used at the beginning and then adjusted by the network so that the next cycle will produce a closer match between the desired and the actual output (Haykin, 1994).

The operations in a processing element started with the computation of the weighted sum of all of the inputs. This weighted sum input, then, was transformed to a working output through a transfer function. The most used transfer function is a sigmoid function. It is used to map the weighted sum of the input values to a reasonable value, before passing the signal into the nodes in next layer. The reasonable values accepted by neural networks are between 0 and 1.

The network learns when it is trained based on a data driven system. Backpropagation network processes the inputs and compares the resulting outputs to the actual outputs. Outputs errors are propagated back through the system, causing the system to readjust the weights. This process runs over and over until continually tweaking the weights.

Once, the network is "taught" how to respond to a set of specific examples, these weights are stored. The network is tested for the accuracy of its predictions of biological activities of SL not included in the training set, using these weight. The dataset which included eigenenergies and dipole moments of 39 SL was divided into two group, one group (training set), which included 33 SL, was used for training the network and another group (testing set), which included six SL, for testing the network prediction. Then, an ANN was trained by using training set to a satisfactory error limit 0.001 and tested by using testing set. This training and testing process were repeated by using different set of training and testing set until all the SL wer predicted once.

Results and Discussion

The basis set used in Gaussian 92 program is STO-3G*, the selection of this basis set is a compromise between qual-

Table 1.

Compound Name	Biological Activity[1] Observed Data	Predicted Data	Error %
Ursiniolide A	5.75	5.68	-1.22
Cinerenin Acetate	5.69	5.71	0.35
Parthenolide	5.52	5.61	1.63
Cinerenin	5.45	5.83	6.97
Cnicin	5.45	5.42	-4.95
Helenalin	5.37	5.19	-3.35
Melampodin A	5.29	5.23	-1.13
Ursiniolide B	5.28	5.32	0.76
Alatolide	5.26	5.22	-0.76
Stizolicin	5.24	5.67	8.21
Centaurepensin	5.22	5.23	0.19
Repin,15-deoxy	5.20	5.23	0.58
Arbusculin B,l β-hydroxy-8β-epoxyangeloyloxy	5.18	5.45	5.21
Santamarin,8β-O-epoxyangelate	5.15	5.14	-0.19
Enhydrin	5.06	5.02	-0.79
Confertiflorin	5.05	5.39	6.73
Repin	5.03	4.91	-2.39
Reynosin,8β-0-2,3-dihydroxy -2-methylbutyrate	5.02	5.01	-0.20
Reynosin,8β-O-epoxyangelate	4.99	5.04	1.00
Salonitenolide	4.99	5.44	9.02
Linifolin A	4.94	4.97	0.61
Santamarin,3,4-cis-α-epoxy-8β-epoxyangeloyloxy	4.75	4.72	-0.63
Glaucolide A	4.68	4.64	-0.85
Grossheinin	4.65	4.57	-1.72
Santamarin,8β-0-(2-hydroxy-ethyl) acrylate	4.75	4.60	0.66
Tatridin B	4.57	4.56	-0.22
Parthenolide, l,10-dihydro-	4.39	4.36	-0.68
Psilostachyin A	4.36	4.29	-1.61
Asperilin	4.24	4.27	0.71
Aromaticin,6α-hydroxy-2, 3-dihydro	4.22	4.16	-1.42
Geigerinin	4.14	4.13	-0.24
Santamarin	4.07	4.09	0.49
Xerantholide	3.99	4.00	0.25
Parthenin	3.89	3.86	-0.77
Vachanic acid,methyl ester	3.70	3.71	0.27
Coronopilin	3.60	3.62	0.56
Burrodin	3.60	3.57	-0.83
Reynosin	3.57	3.54	-0.84
Schkuhriolide	3.56	3.53	-0.84

[1]Biological activity is the Log ($1/IC_{50}$) where IC_{50} is the micromolar concentration of SL that will inhibit the release of serotonin by 50%. Values were taken from Marles et al. (1995).

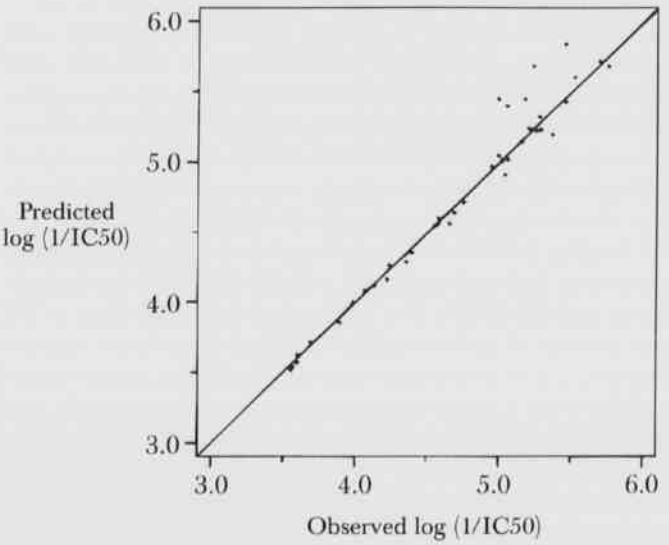

Fig. 2. Correlation between the actual values and the predicted values of biological activities of SL by using ANN.

ity of the results and availability of computer resources. More detailed basis sets such as 6-31G, that could potentially provide higher quality results. However, it produced files larger than the two-gigabyte limit that the computer operating system (IRIX 5.3) could handle.

ANNs analysis of the antimigraine activity of SL was performed as indicated in the methods section, with a training set of 33 SL and a testing set of 6 SL. Several runs were conducted in this manner. The results of this analysis are presented in Table 1, and a plot of predicted versus observed activity is presented in Fig. 2. It can be observed that the percent error for prediction of antimigraine activity of SL ranged from a minimum of -0.19 to a maximum of -9.02. These errors are very low and most of them are probably smaller than experimental error. Figure 2 also showed that ANNs did very well in correlating the structural information and their antimigraine activity of SL since most of the data are in the straight line in this plot.

Conclusions

In this research, we have demonstrated the use of ANNs in mapping quantum mechanical parameters to antimigraine activities of SL. ANNs were found to be very successful in correlating the SL's structure with their antimigraine activity, although they provided very limited information on the particular requirements for maximum activity.

Additional studies on the structure-toxicity relationship studies of the SL using ANNs should be very helpful in identifying or designing SL with high activity and low toxic potential. Also, this method might be applied to map quantum mechanical parameters to other chemical, physical and biological properties of different groups of molecules.

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Acidity Studies of Deuterated Acids and Bases Commonly Used as Buffers in NMR Studies

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Abstract

Structure based drug development is currently considered to be an important strategy for drug discovery. This strategy requires that critical knowledge of the three dimensional binding site on receptor molecules be known. NMR studies are frequently employed to ascertain important structural data on individual proteins as well as complexes of proteins with ligands. Deuterium labeled acids and bases are frequently used as buffers in deuterium oxide solutions for NMR studies on the structural conformations of bioactive molecules. Since pH is an important factor in any study of the confirmational and stereochemical aspects of biologically active molecules, deuterated buffers are an essential part of the NMR experiments. However, the ionization constant for deuterium oxide (1.95×10^{-15}) is significantly different from that of water. Therefore, a pH comparison of deuterium-labeled acids and bases in deuterium oxide with nondeuterated aqueous acids and bases was conducted. Titration curve comparisons for deuterated and non-deuterated hydrochloric acid, acetic acid, sodium formate, and TRIS (tris[hydroxymethyl]amino methane) are described. Also, the average pK_as of deuterated and non-deuterated acetic acid, formic acid, and TRIS are compared.

Introduction

Over the last 20 years the development of structural chemistry and biochemistry has provided more and more detailed information about the chemical nature of living organisms. Each new insight into the chemical make-up of organisms provides additional guidance for the construction of compounds that have a desirable pharmacological effect. Prior to some of the recent advances in structural chemistry, the discovery of new drugs was made largely through serendipity. In many cases systematic searches for new drugs were made by screening compounds through biological assays. Once a compound was found to have a desirable pharmacological effect, it became a lead compound. However, simply determining that a compound exerts a biological effect did not automatically lead to the development of a new drug. Transport of the compound to the site of action, specificity of the interaction of the compound with a target receptor in an environment where a multitude of other receptors are present, and the economics of synthesizing, investigating, and marketing the compound were all to be considered in developing a promising lead compound into a drug. This process is limited by budget, is not guaranteed to produce a favorable result, and may miss potential drugs if the assay chosen is not appropriate. Although random screening has led to the discovery of several antibiotics and other important drugs, it is clearly inefficient.

New knowledge of biological systems could suggest new approaches to drug discovery and development. This is especially true if specific macromolecules can be identified as the receptor or target for a possible drug. Critical knowledge about the three dimensional nature of the binding site of the receptor is of greatest value. X-ray and NMR methods are now frequently used to provide these three dimensional structures of individual proteins and complexes of proteins with ligands at a rate of several hundred per year (Perutz, 1992). In 1996, the protein data base at Brookhaven National Laboratories contained over 4000 structures of proteins and nucleic acids. There is considerable evidence that the tertiary structure of a protein observed in a X-ray crystal structure is similar to the average structure of the protein in solution as observed by NMR. However, the consensus at present seems to be that the X-ray crystal structures of nucleic acids are imperfect when compared to the average structures of these molecules as seen by NMR. Accurate three-dimensional structure information of macromolecule receptors is critical to structure-based drug development.

Techniques for interpreting NMR spectral data and the reliability of the structures proposed from these data have been extensively described (Braulin, 1995; Billeter, 1995; Markus et al., 1994). NMR methods of structure determination use non-crystalline samples, typically aqueous solutions. The solution conditions (pH, temperature, nature and concentration of buffers or added salts, and con-

centration of the macromolecule) can be varied. NMR methods are unique in that they can be used to detect the presence of two or more major conformations (Schaefer et al., 1995; Cheong and Lee, 1995) and to obtain quantitative information on dynamic processes, including the rates of confirmational interconversion, rates of exchange of labile protons (particularly amide NH protons), as well as the rates of backbone and side chain motions (Markus et al, 1994; Houk et al., 1994). Like many other spectroscopic methods, NMR can be used in titration experiments to demonstrate the stoichiometry of ligand-receptor interaction and to provide a value for the equilibrium constant that characterizes the formation and dissociation of the receptor-ligand complexes. Since these experiments can not only provide three dimensional structural information but can also indicate structural flexibility, the knowledge base for discovery of new pharmaceutical agents by structure based drug design can be considerably expanded by NMR.

Virtually all molecules in a biological system include protons in their structure, and the NMR signals from these hydrogens are readily detectable. Although the spectral lines for ^{13}C and ^{15}N signals from a biomolecule can be resolved better than proton NMR signals from the same molecule, ^{13}C and ^{15}N are present only in 1.1% and 0.37% natural abundance, respectively. The amounts of these isotopes can be enriched to essentially 100% by appropriate synthetic efforts. However, this can be costly and time consuming. Therefore, most NMR experiments focus on ^{1}H NMR in deuterium-labeled solvents. In order to differentiate the biomolecule of interest from the solvent, NMR solvents generally consist of deuterium oxide buffered by deuterium labeled weak acids and bases. However, the ionization constant for deuterium oxide ($K_{Deuterium\ oxide}$), reported to be 1.95×10^{-15} at 25°C (Merck Index, 1989), is significantly different from the ionization of water ($K_w = 1.0 \times 10^{-14}$ at 25°C). The ionization constant for deuterium oxide (D_2O) was calculated in a similar fashion as K_{Water} (the product of the D_3O^+ concentration and the ODconcentration). Little or no information is available on the K_a and K_b values for the deuterated form of commonly used buffers, such as acetic acid-d_4, sodium formate-d, TRIS-d_3, and phosphoric acid-d_3. Therefore, the question arises as to whether there is a variation in the pH of solutions prepared in deuterated and non-deuterated buffers. Even a small change in pH arising from the use of deuterated buffers in deuterium oxide could cause a significant effect on the three dimensional structure of the protein or other biomolecule under investigation. There have been reports in the literature of primary and secondary deuterium isotope effects on the ^{13}C NMR chemical shifts of aldehydes (Vjanic et al., 1995), carboxylic acids (Yonemitsu et al., 1995), and intramolecularly hydrogen-bonded olefins (Hasen et al., 1995), as well as the amide bonds of proteins (Markus et al., 1994) in deuterium oxide solutions. These deuterium isotope chemical shift effects may be related to a pH deuterium effect. Therefore, we have undertaken an investigation of the effects of deuterium on pH. The results of this investigation are reported below.

Materials and Methods

Materials Used

Hydrochloric Acid Concentrate
(Fisher SA49-100) standard
volumetric solution

Sodium Hydroxide Concentrate
(Fisher SS267-100) standard
volumetric solution

Acetic Acid Concentrate
(Anachemia 206-06) standard
volumetric solution

Formic Acid, Sodium Salt
(Sigma F-6502) anhydrous 99.9+%

TRIS (Tris[hydroxymethyl]amino methane
(SigmaT-1503) 99.9%

Deionized Water

Deuterium Chloride, 37 wt %
solution in Deuterium Oxide
(Aldrich 22,707-2), 99.5 atom % D

Sodium Deuteroxide, 40 wt %
solution in Deuterium Oxide
(Aldrich 37,207-2)

Acetic-d_3 acid-d, 99.9 atom % D
(Aldrich 23,7000)

Formic-d, Sodium Salt, 98 atom%D
(Aldrich 37,384-2) anhydrous

TRIS-d_3 (Tris[hydroxy-dmethyl]
amino - d_2 -methane
(Aldrich 32,994-0), 98 atom %D

Deuterium Oxide, 100.0 atom %D
(Aldrich 15, 189-0)

A standardized (Aldrich Zl l, 343-3) calomel combination pH electrode (ultra-thin, long stem) accompanied by a

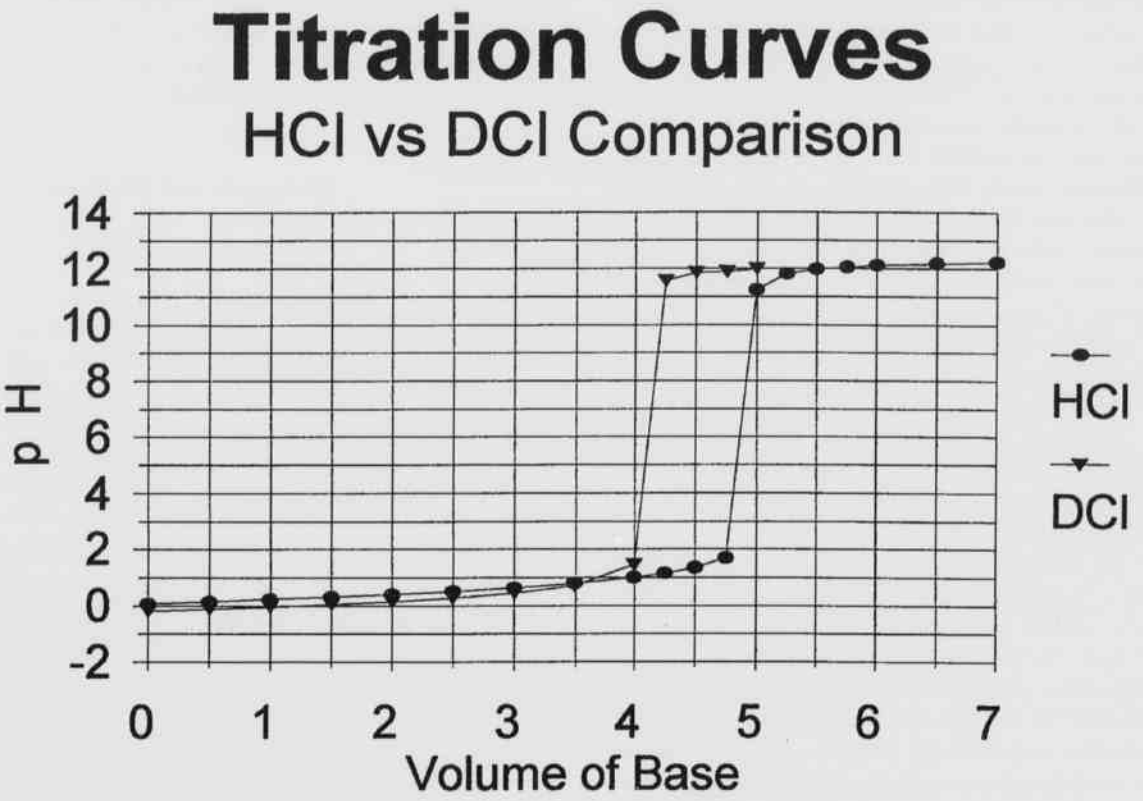

Fig. 1. Titration curve for HC1/DC1 comparison.

temperature compensator probe was used in all titrations. American Scientific Products pH reference buffer solutions of pH 4 and 7 were used in the standardization. All titrations were repeated a minimum of three times for consistency.

Titration Method 1.--This method was used for all compounds purchased as liquids or solutions (sodium hydroxide, sodium deuteroxide, hydrochloric acid, deuterium chloride, acetic acid, and acetic acid-d_4). 5.00 mL of a 1.00 M acid solution (HCl, DCl, acetic acid, or acetic acid-d_4) was transferred by volumetric pipette (Pyrex No. 7102, 5.00 mL) into a 30 mL conical shaped glass centrifuge tube. A small stir bar was added to the centrifuge tube, and the tube was placed in a circulating water bath (22° C). The long, narrow pH electrode was placed in the centrifuge tube and the temperature compensator probe was placed in the water bath. A 10.00 mL buret (increments = 0.05 mL) was filled with exactly 1.00 M base solution (sodium hydroxide in deionized water or sodium deuteroxide in D_2O). The pH was recorded with each 0.10 mL addition of the base solutions to the appropriate acid solutions. Hydrochloric acid and acetic acid solutions in deionized water were titrated with a 1.00 M sodium hydroxide solution in deionized water, whereas, deuterium chloride and acetic acid-d_4 solutions in D_2O were titrated with a 1.00 M sodium deuteroxid solution in D_2O.

Titration Method 2.--This method was used for all compounds purchased as solids (sodium formate, sodium formate-d, TRIS, and TRIS-d_3). Each base was dried for 1 hour in an oven (105° C), and then cooled in a desiccator for 15 minutes. Each base was then massed into conical shaped centrifuge tubes. Three samples, each appropriated to give 5 mL of a 1.0 M solution, of each base were prepared. The samples were then dissolved in about 5 mL of either deionized water or deuterium oxide. The ~1.0 M base solutions were placed in a water bath (22° C). A long thin pH electrode was placed in the centrifuge tube and the temperature compensator probe was placed in the water bath. A 10.00 mL buret (increments = 0.05 mL) was filled with exactly 1.00 M acid solution (either HCl in deionized water or DCl in deuterium oxide). The pH was recorded with every 0.10 mL addition of the acid to the centrifuge tube. Sodium formate and TRIS were titrated with 1.00 M hydrochloric acid in deionized water, whereas, sodium formate-d and TRISd_3 were titrated with 1.00 M deuterium chloride in deuterium oxide.

Results and Discussion

Figure 1 shows a plot of a representative titration curve for both 1.0 M aqueous hydrochloric acid with 1.0 M aque-

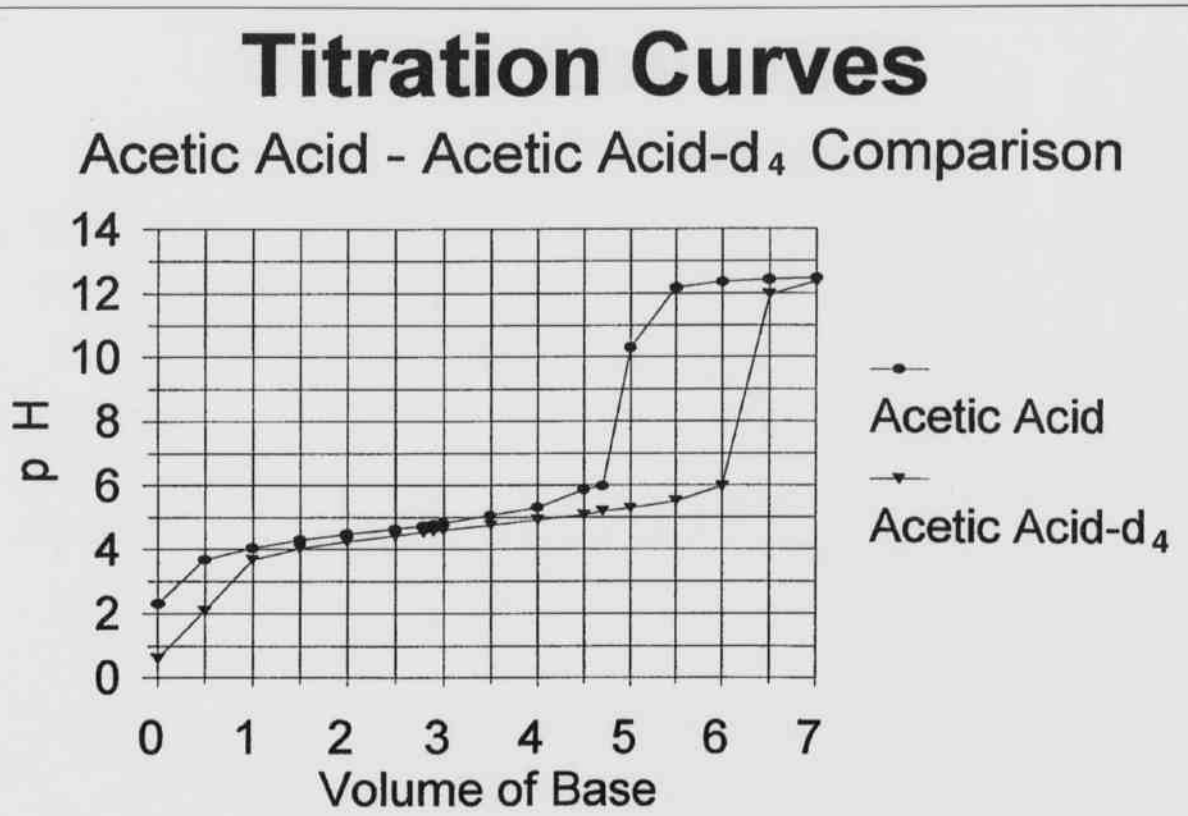

Fig. 2. Titration curve for acetic acid/acetic acid-d_4 comparison.

ous sodium hydroxide as well as for 1.0 M deuterium chloride in D_2O with 1.0 M sodium deuteroxide in D_2O. A significant difference in the equivalence points can be seen in the titration curves of the deuterated and non-deuterated strong acids. Figure 2 shows a similar plot of a representative titration curve for 1.0 M aqueous acetic acid titrated with 1.0 M aqueous sodium hydroxide as well as for the titration of 1.0 M acetic acid-d_4 in D_2O with 1.0 M sodium deuteroxide in D_2O. In both Fig. 1 (HCl/DCl comparisons) and Fig. 2 (acetic acid/acetic acid-d_4 comparison), there are major differences in the equivalence points for the deuterated vs. the non-deuterated acid. Representative titration curves for formic acid-d in D_2O and aqueous formic acid solutions titrated with deuterium chloride and hydrochloric acid solutions, respectively (Fig. 3), and for the titrations of deuterated and non-deuterated TRIS (tris[hydroxymethyl]-aminomethane) solutions with solutions of deuterium chloride and hydrochloric acid (Fig. 4) are shown below. Each of these representative titration curves (Figs. 3 and 4) of these weak bases shows differences in the equivalence points for the deuterated and nondeuterated bases.

Table 1 shows the pK_a's calculated from the titration data for each of the deuterated and non-deuterated acids and bases. The K_a's are determined from several titration curves utilizing the one half equivalence point on the titration curves. The average pK_a is shown on the right side of Table 1. In each case the average pK_a is somewhat higher for the deuterated acid or base in D_2O than the average pK_a for the non-deuterated aqueous form of the acid or base. The differences in the average pK_a's are especially significant for sodium formate-d/sodium formate and TRIS-d_3/TRIS. This increase in the average pK_a for the deuterated acids and bases may result from a difference in the ionization constants of deuterium oxide (1.95×10^{-15} at 25°C) and water (1.00×10^{-14} at 25°C). Deuterium oxide is significantly less ionized than normal distilled water; therefore, weak acids and bases may also be significantly less ionized when dissolved in deuterium oxide.

Conclusions

From the results of our study, thus far, it is apparent that the use of deuterated weak acids or bases as buffers in deuterium oxide solutions will have some effect on the pH of the solution. Therefore, it may be extremely important to measure the pH of all NMR samples containing large proteins or other biomolecules in deuterated buffered solvents

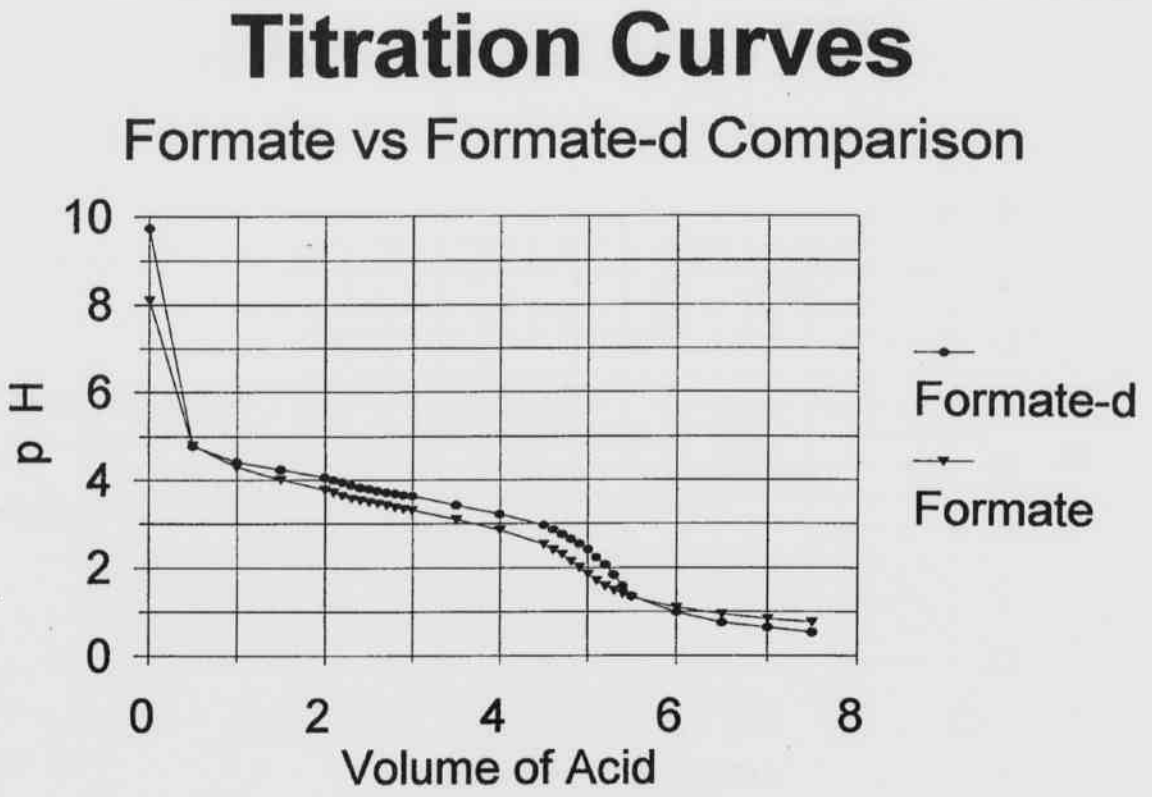

Fig. 3. Titratium curve for formate-d/formate comparison.

before collecting data on the three-dimensional structure.

ACKNOWLEDGMENTS.—The authors wish to thank the National Science Foundation (RUI Program), the SILO (SURF Program), and the University of Arkansas at Monticello-Faculty Research Committee for the funding of this project.

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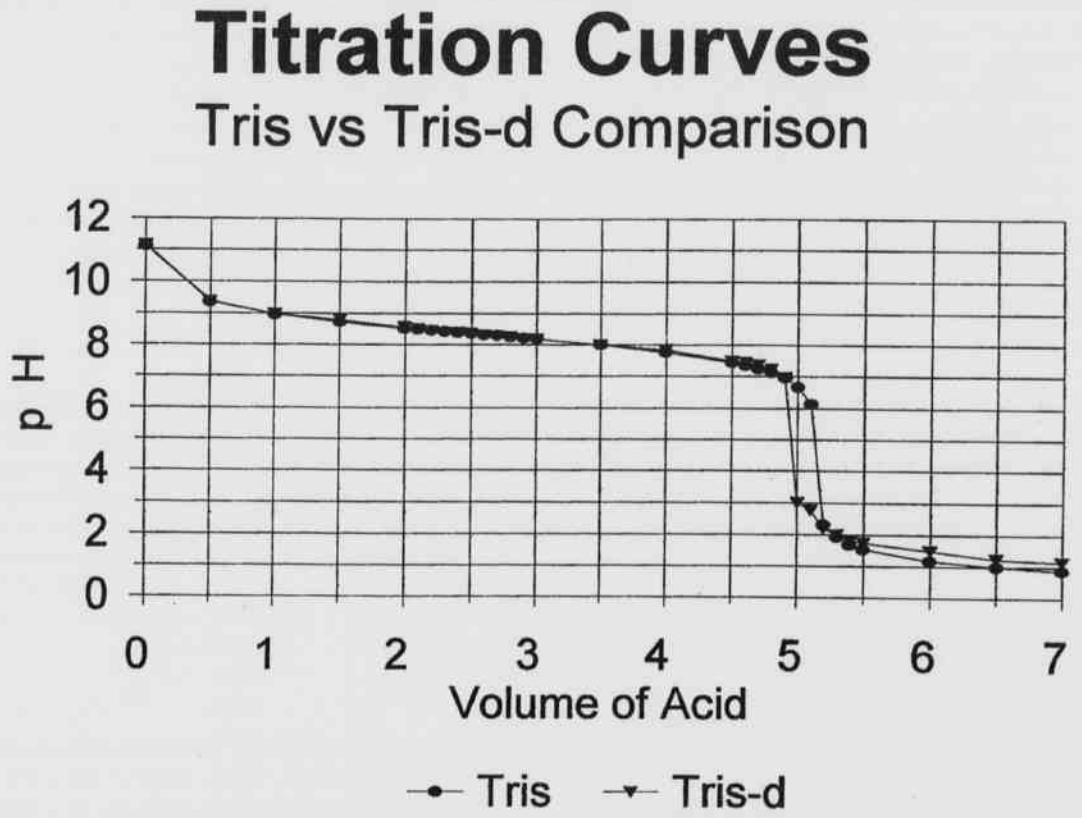

Fig. 4. Titration curve for TRIS/TRIS-d_3 comparison.

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Table 1. pk_a data for deuterated and non-deuterated acids and bases.

run	compound	pK_a	average pK_a
I	acetic acid-d_4	4.66	
II	acetic acid-d_4	4.65	4.65
III	acetic acid-d_4	4.65	
I	acetic acid	4.64	
II	acetic acid	4.62	4.63
III	acetic acid	4.63	
I	sodium formate-d	3.63	
II	sodium formate-d	3.63	3.63
III	sodium formate-d	3.63	
I	sodium formate	3.54	
II	sodium formate	3.53	3.54
III	sodium formate	3.54	
I	TRIS-d_3	8.37	
II	TRIS-d_3	8.36	8.37
III	TRIS-d_3	8.37	
I	TRIS	8.28	
II	TRIS	8.33	8.30
III	TRIS	8.30	

Artificial Neural Networks Used to Predict Electrical Properties of Polymers

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Abstract

The ability to predict properties of molecules prior to their synthesis can be of great importance in optimizing their design. Substantial savings in time as well as cost can be achieved if some desired properties can be predicted prior to the synthesis of the molecule. The outer orbitals of a molecule are primarily responsible for many different properties of the molecules. These outer orbital parameters can be utilized by an intelligent computing system like an Artificial Neural Network to extract necessary knowledge about the properties of the molecule. An Artificial Neural Network was trained to extract electrical parameters of several polymers. The former was then tested using a number of molecules set aside (not used in training) solely for this purpose.

Introduction

The ability to predict physical, chemical and biological properties of molecules is of great value in optimizing their design, modification and processing. Both time and cost of synthesis can be saved if the properties of the molecules are predicted accurately prior to their synthesis.

In the present day approach, a molecule is designed and optimized first using different types of quantum mechanical calculations. The molecule is then physically synthesized in the laboratory before its properties can be tested. If the test for the properties fails, the entire molecule is generally discarded. This means a total waste of time and money for the synthesis stage. This new approach attempts to optimize the entire process and uses artificial intelligence techniques to predict the required properties from the quantum mechanical calculations.

It is well known that the outer orbitals of a molecule are the most active ones and are primarily responsible for the major chemical, physical and biological properties of the molecule. It was, thus, assumed that some extremely useful information might be embedded in various molecular orbital parameters that can readily be obtained usingthe well known SCF-MO quantum mechanical calculations. These calculations were performed on the available molecules using ab initio Self-Consistent Field - Molecular Orbital (SCF-MO) calculations (Darsey et al., 1993; Soman et al., 1995).

In the next stage, an Artificial Neural Network (ANN) was trained on different properties of different sets of molecules relating the quantum mechanical parameters obtained in the previous stage. These neural networks were tested using, a number of molecules set aside (not used in training) solely for this purpose.

Methodology

Artificial Neural Networks.--The fundamental processing element of a neural network is a neuron. This building block of human awareness encompasses a few general capabilities. Basically, a biological neuron receives inputs from other sources, combines them in some way, performs a generally nonlinear operation on the result, and then outputs the final result. But currently, the goal of artificial neural networks is not the grandiose recreation of the brain. On the contrary, neural network researchers are seeking an understanding of nature's capabilities for which people can engineer solutions to problems that have not been solved by traditional computing.

To do this, the basic units of neural networks, the artificial neurons, simulate the four basic functions of natural neurons. Currently, neural networks are the simple clustering of primitive artificial neurons. This clustering occurs by creating layers which are then connected to one another. How these layers connect is the other part of the "art" of engineering networks to resolve real world problems.

Although there are useful networks which contain only one layer, or even one element, most applications require networks that contain at least the three normal types of lay-

ers - input, hidden, and output (Fig. 1). The layer of input neurons receives the data either from input files or directly from electronic sensors in real-time applications (Mitra and Darsey, 1995). The output layer sends information directly to the outside world, to a secondary computer process, or to other devices such as a mechanical control system. Between these two layers can be many hidden layers. These internal layers contain many of the neurons in various interconnected structures. The inputs and outputs of each of these hidden neurons simply go to other neurons (Baba, 1989; Chui, 1992).

Table 1.

Dieelectric Constants

Name of Polymer	Observed Data	Predicted Data	Error %
Poly(tetrafluoroethylene)	2.00	1.87	6.50
Polyisobutylene	2.23	2.32	-4.00
Polyethylene	2.30	2.19	4.80
Polypropylene	2.30	2.41	-4.80
Polyisoprene	2.40	2.37	1.70
Polybutadiene	2.51	2.44	2.80
Polysiloxane	3.04	2.87	5.60
Poly(vinyl acetate)	3.50	3.39	3.10
Poly(methyl methacrylate)	3.60	3.06	15.0
Poly(oxymethylene)	3.70	2.54	31.4
Polyacrylonitrile	6.50	4.12	36.6
Poly(vinyl alcohol)	7.80	3.25	58.3
Poly(vinylidenefluoride)	8.40	3.04	63.8

Fig. 1. Architecture of an Artificial Neural Network with one hidden layer.

In most networks each neuron in a hidden layer receives the signals from all of the neurons in a layer above it, typically an input layer. After a neuron performs its function it passes its output to all of the neurons in the layer below it, providing a feedforward path to the output.

Once a network has been structured for a particular application, that network is ready to be trained. To start this process the initial weights are chosen randomly. Then, the training, or learning, begins. There are two approaches to training - supervised and unsupervised. Supervised training involves a mechanism of providing the network with the desired output either by manually "grading" the network's performance or by providing the desired outputs with the inputs (Crooks, 1992). In unsupervised training where the network has to make sense of the inputs without outside help. The vast bulk of networks utilize supervised training.

Artificial Neural Networks for the Prediction of Dielectric Constant of Polymers.--A multilayered backpropagation network was designed to achieve this goal. The network had three layers - the input layer with 31 input nodes (30 eigenenergies and dipole moment for each polymer), the output layer with one output node (corresponding to the property predicted dielectric constant) and a hidden layer with eight nodes.

Results and Discussion

The eigenenergies of the lowest 15 unoccupied molecular orbitals, the 15 highest occupied molecular orbitals and the dipole moment of each polymer were obtained by using quantum mechanical calculations Gaussian 86 and 92 programs. STO-3G* was used as the basis set and POP=REGULAR was used as a keyword. The dielectric constants of polymers used in this study were obtained from the literature (Brandrup and Immergut, 1975).

Out of the available 14 conductive polymers, 13 were used for training and one was left for testing or to validate the training. In the next run, a different set of 13 polymers was used for training, and the remaining polymer was used for testing. A total of 14 sets of training was conducted in this manner and the results have been presented in Table 1 and Fig. 2. As observed from table 1, 9 out of 14 polymers, which have smaller dielectric constants, had less than 10% error in the prediction of the dielectric constants. Figure 1 presents

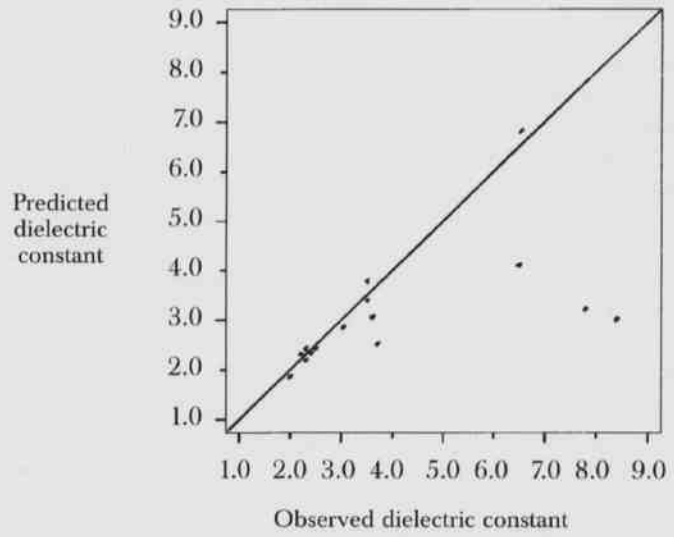

Fig. 2. Correlation between the actual values of dielectric constants and the values predicted by the Artificial Neural Netowrk.

the same information. However, when the dielectric constant data was large, the percent error was also getting large. The reason for this, we feel, was the small number of compounds tested. If you don't provide enough information to train the network, it won't learn properly.

Conclusions

So far the results obtained from using neural networks are good enough to justify further work on making a better association between molecular orbital and the electric properties of polymers. In particular efforts should be made to increase the number of polymers in the dataset and also to include a wider range of dielectric constants.

A combination of quantum mechanical and artificial intelligence techniques has been applied in this work to predict the dielectric constant of conductive polymers. If the process of prediction becomes more reliable, the technique can lead to substantial savings in time and cost. This technique might, as well, be tried on other electrical and non-electrical properties of both polymeric and non-polymeric materials.

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Effects of Retained Pine and Hardwood Basal Areas on Percent Cover of Plants Utilized by Bobwhite Quail

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Abstract

Percent cover of seven forage species utilized by bobwhite quail (*Colinus virginianus*) was determined before thinning and 2 and 4 years after thinning a 35-year-old loblolly pine-hardwood stand. Combinations of three loblolly pine (15, 18, and 21 m^2/ha) and three hardwood (0, 3.5, and 7 m^2/ha) basal areas were replicated three times. Percent cover was determined for American beautyberry (*Callicarpa americana*), blackberry (*Rubus* spp.), tick trefoil (*Desmodium* spp.), lespedeza (*Lespedeza* spp.), panic grass (*Panicum* spp.), yellow wood sorrel (*Oxalis stricta*), and three-seeded mercury (*Acalypha* spp.). Percent cover of American beautyberry and blackberry increased with time. Tick trefoil and panic grass were negatively related to time after thinning. However, lespedeza, yellow wood sorrel, and three-seeded mercury were not influenced significantly by time after thinning. Blackberry and panic grass were negatively related to pine basal area, while all other plant species were not affected. Three-seeded mercury was the only species not negatively related to hardwood basal area. Canopy cover and relative light intensity in the understory demonstrated an inverse relationship.

Introduction

Northern bobwhite quail (*Colinus virginianus*) populations are declining throughout the southeastern United States (Klimstra, 1982). Historically, bobwhite quail have inhabited primarily agricultural lands which provide a diversity of habitats such as crop fields, fence rows, and pastures. However, availability of this type of habitat in the Southeast has been affected by reduction or abandonment of farmlands (Sorrow and Webb, 1982). Thus, bobwhite quail in the southeastern United States primarily occur in pine and mixed pine-hardwood forests (Bell et al., 1985). Consequently, effects of timber management practices on bobwhite quail habitat can have a profound effect on their numbers. Plants producing seeds and soft mast can be influenced dramatically by prescribed fire, overstory canopy removal, and other silvicultural treatments. Seeds and soft mast provide important energy sources for bobwhite quail throughout the year.

Approximately 31% of private forest land in Arkansas is owned by forest industries (Beltz et al., 1992). These forested lands are often intensely managed with clearcuts and short rotations that are not always favorable to bobwhite quail. Young clearcut stands, reforested as even-aged pine plantations, initially provide adequate to excellent food sources for bobwhite quail (Sorrow and Webb, 1982). After 2-3 years, however, these stands provide little foraging opportunity for bobwhite quail as many of the seed and soft mast producing plants are shaded out or out competed by increasing woody plants. Increasing litter depth also inhibits bobwhite quail from foraging efficiently on available food sources. Much of the nonindustrial private forest land in Arkansas is unmanaged, resulting in poor habitat for bobwhite quail. Overstory stocking in many of these stands is too high to permit adequate sunlight to reach the forest floor. Thick litter depth and sparse understory vegetation common in these stands impede bobwhite quail from foraging efficiently.

Silvicultural practices such as prescribed burning and thinning can be used to improve bobwhite quail habitat (Landers and Mueller, 1986). Controlled burns reduce litter build up, release nutrients, and promote herbaceous plant growth. Thinning reduces stand basal area, which promotes herbaceous plant growth by opening the stand's canopy allowing additional sunlight to reach the understory. Recommended thinning of a pine stand for improving bobwhite quail habitat is to retain a basal area in ft^2/acre numerically equal to the site index (tree height in feet at fifty years

of age) minus a value of 25 (Landers and Mueller, 1986). Control of midstory hardwoods, which produce twice as much shading as the same pine basal area, can also help improve bobwhite quail habitat (Tappe et al., 1993). Midstory hardwoods that occur in pine dominated stands are generally too small in size and low in vigor to produce hard mast which could supplement a bobwhite quail's diet of insects, seeds, and soft mast (Landers and Mueller, 1986). The objective of this study was to determine how residual pine and hardwood basal areas after a thinning operation affect the herbaceous plants that produce seeds, soft mast, and forage for bobwhite quail.

Matrials and Methods

Study Area.--The study was established in a natural, even-aged, 35-year-old loblolly pine (*Pinus taeda*)-hardwood stand located in the School Forest of the University of Arkansas at Monticello, Drew County, Arkansas. Soils of the area were mapped as Henry (Typic Fragiaqualfs) and Calloway (Flossaquic Fragiaqualfs) series (Larance et al., 1976). Both soils have silt loam surfaces and were formed on windblown silt. These poorly drained soils occur on broad upland flats and have a site index of 28 m at 50 years for loblolly pine.

The present stand was naturally regenerated from an existing hardwood-pine stand in the early 1950's; the hardwood component was killed, and a new loblolly pine stand established from seeds produced by residual trees. A few remnants of the original forest stand still existed prior to study installation. This forest stand was typical of many unmanaged pine stands in Arkansas, which have developed a dense hardwood midstory. Before thinning, the loblolly pine basal area averaged 27 m^2 /ha, and the hardwood basal area averaged 8 m^2/ha. Most hardwoods formed a uniform midstory with occasional individuals extending into the loblolly pine canopy. The hardwood component was principally willow and water oak (*Quercus phellos* and *Q. nigra*, respectively) with lesser amounts of southern red oak (*Q. falcata*) and sweetgum (*Liquidambar styraciflua*). Stem quality of the loblolly pine component was sometimes poor because of past damage from ice storms and stem cankers. Some of the hardwood stems were hollow or had other obvious stem defects.

Study Design.--Twenty-seven circular, 0.08-ha plots were established with a 10-m isolation strip around each, creating overall plots of 0.21 ha. Systematically located within each 0.08-ha plot were 25 (1 x 1m) subplots. Treatments reduced the overstory basal area to three levels for loblolly pine (15, 18, and 21 m^2/ha in trees ≥ 9.1 cm in diameter at breast height [d.b.h.]) and three levels for hardwoods (0, 3.5, and 7 m^2/ha). Treatments were randomly assigned as much as possible in a randomized block design with three blocks. Some plots, especially those with the highest level of hardwood retention, were assigned to meet specific targets.

The pine component of each plot was harvested as a free thinning. Most of the thinned trees were below the stand's mean d.b.h., but a few low quality dominant and codominants were thinned. Thinning of the hardwood component favored retention of the larger and better quality oaks. The plots and their adjoining isolation strips were thinned to the same basal areas. The areas between the combined plots and isolation strips were thinned to 18 m^2/ha of pine basal area and a component of desirable hardwoods.

All trees were harvested as pulpwood in 1.5-m bolts to minimize damage to the residual stand. Logging began in fall of 1988 but was terminated during the early winter because of wet soil conditions. Loblolly pine thinning was virtually completed by late spring of 1989, but unusually wet weather during the summer prevented completion of the hardwood thinning until late summer of 1989. Thus, logging continued intermittently for about 1 year with the pine component being mostly thinned before the 1989 growing season and the hardwoods being thinned at the end of the 1989 growing season. During late winter and early spring of 1990, all sub-merchantable hardwoods ≥ 2.5 cm d.b.h. were killed with stem-injected herbicides.

Percent cover before thinning and 2 and 4 years after thinning was ocularly estimated (Mueller-Dombois and Ellenberg, 1974) for seven preferred bobwhite quail food plants less than 1 m in height using the 25 subplots on each plot. Species included American beautyberry (*Callicarpa americana*), blackberry (*Rubus* spp.), tick trefoil (*Desmodium* spp.), lespedeza (*Lespedeza* spp.), panic grass (*Panicum* spp.), yellow wood sorrel (*Oxalis stricta*), and three-seeded mercury (*Acalypha* spp.). Mean percent cover was calculated for each species by treatment plot and year after thinning. An inventory was conducted after completion of thinning to determine overstory basal area. Canopy cover of the overstory was determined at each subplot using a spherical densiometer. Photosynthetically active radiation (light intensity) was determined at a height of 1.4 m on 39 temporary points systematically located within each plot during clear sky conditions on 31 July 1991 and 25 July 1993 using a sunfleck ceptometer. All measurements were taken within ± 1.5 hr of solar noon. Measurements also were taken in full sunlight so that relative percent light intensity of full sunlight could be calculated.

Data Analysis.--The basal area of individual plots varied within a treatment class because of (1) tree mortality from logging damage and natural causes, (2) growth during study installation, and (3) the inability to precisely control basal areas on small plots. After study installation, basal areas varied by a mean of 1.5 m^2/ha within treatment classes for both pines and hardwoods. Because of this variation,

data were analyzed using regression. This allowed using the actual basal area of each plot rather than its class designation. Several candidate equations were evaluated for use in analyzing the data. Based on residual plots and fit indices, we selected the following form:

$$Y = \exp (b_0 + b_1T + b_2P + b_3H)$$

where Y is the specific response variable, T is the time after thinning in years, P and H are the residual pine and hardwood basal areas, respectively, and the b_i's are coefficients to be determined. Coefficients were calculated by nonlinear least squared regression using the SAS procedure MODEL (SAS Institute, 1988). Data for fitting our equation were the mean percent cover of individual species on each of the 27 plots evaluated at 2 and 4 years after thinning. This provided a total of 54 observations for each plant species. Variables were eliminated from the full model if their coefficient did not significantly differ from zero at a probability level of $P \leq 0.10$. The fit index reported for these equations is analogous to the coefficient of determination.

Results

Before thinning, coverage of American beautyberry, blackberry, and tick trefoil averaged less than 1% across our study area (Fig. 1). Lespedeza, panic grass, yellow wood sorrel, and three-seeded mercury were not observed prior to thinning. Positive regression coefficients (Table1) demonstrated that the woody plants, American beautyberry and blackberry, increased with time (Fig. 1) through four years. The herbaceous plants tick trefoil and panic grass were negatively influenced by time as indicated by their negative regression coefficients. However, the other herbaceous plants, lespedeza, yellow wood sorrel, and three-seeded mercury, were not influenced significantly by time since thinning. Blackberry and panic grass were influenced negatively by increasing pine basal area; all other plant species were not effected. Three-seeded mercury was the only plant species studied that was not negatively influenced by increasing hardwood basal area. Canopy cover and relative light intensity demonstrated an inverse relationship, with light intensity decreasing as pine and hardwood canopy cover increased (Fig. 2). Increases in canopy cover from 2 - 4 years were greatest for plots with the lowest basal areas.

Table 1. Regression coefficients and associated statistics for determining percent cover of plant species important as food sources for bobwhite quail from the number of years after stand thinning, residual pine basal area, and hardwood basal area in a thinned 35-year-old loblolly pine-hardwood stand in southeastern Arkansas. Also shown are regression coefficients for determining canopy cover and relative light intensity.

Response variable	Regression coefficients[1]				Mean coverage[2]	RMSE	Fit index
	b_0	b_1	b_2	b_3			
Plant species							
Blackberry	3.320	0.426	-0.137	-0.346	3.90	2.12	0.82
Panic grass	4.600	-0.338	-0.104	-0.133	3.66	3.08	0.34
American beautyberry	0.813	0.225	ns	-0.158	2.80	2.68	0.23
Lespedeza	-0.296	ns	ns	-0.271	0.37	0.53	0.21
Yellow wood sorrel	-0.648	ns	ns	-0.200	0.29	0.27	0.30
Tick trefoil	ns	-0.334	ns	-0.149	0.25	0.38	0.13
Three-seeded mercury	ns	ns	ns	ns	0.14	---	---
Canopy cover	4.100	0.037	0.010	0.021	88.30	5.89	0.59
Light intensity	5.276	-0.057	-0.080	-0.155	23.10	4.60	0.87

[1]The equation is $Y = \exp (b_0 + b_1T + b_2P + b_3H)$ where Y is the specified response variable, T is the time after thinning in years, P and H are the residual pine and hardwood basal areas, respectively, in m^2/ha after thinning. Shown coefficients were significant at $P \leq 0.10$. Non-significant coefficients are indicated by ns.

[2]Mean percent cover of individual species calculated from 27 plots evaluated at 2 and 4 years after thinning. This provided a total of 54 observations for each plant species.

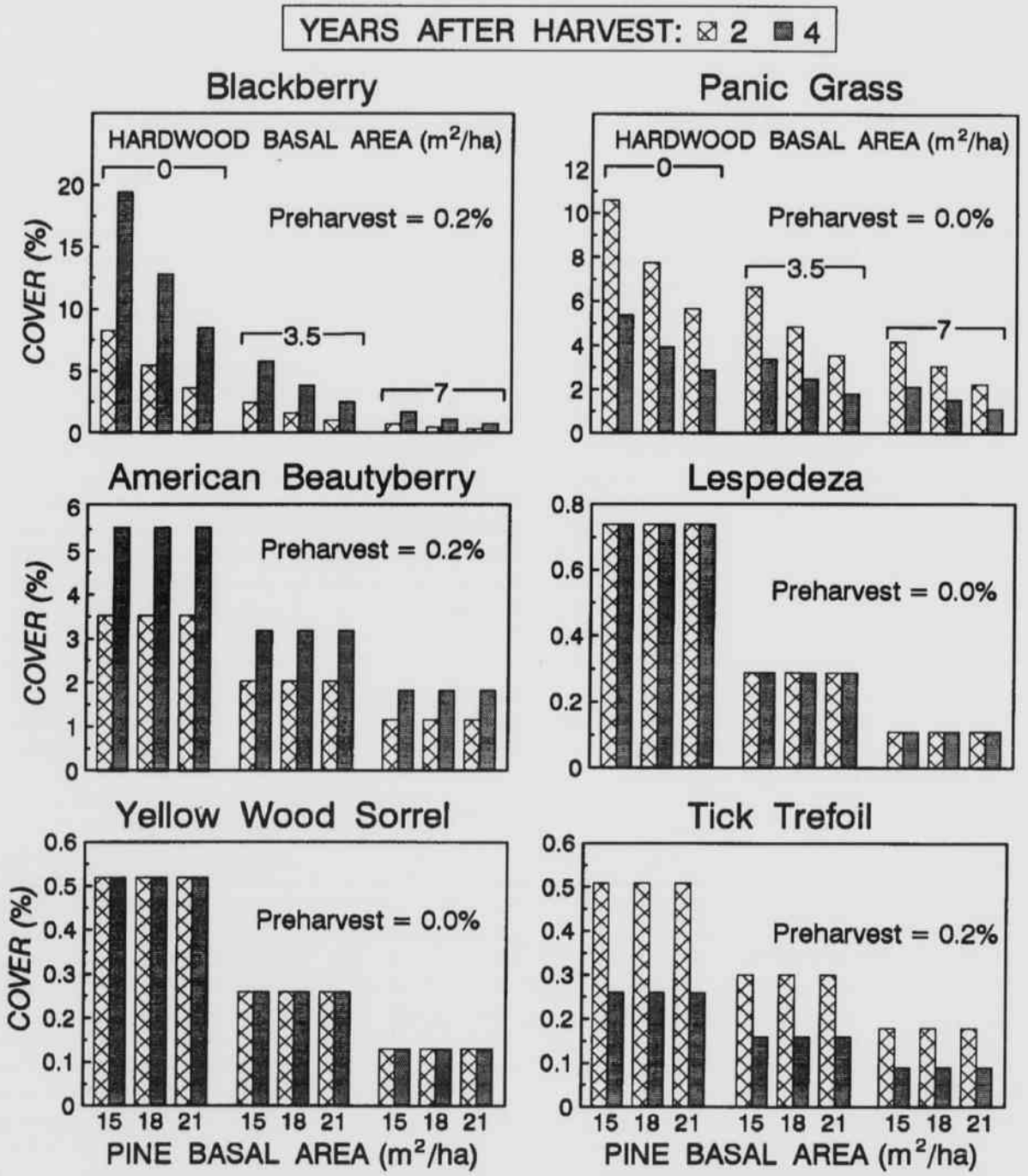

Fig. 1. Effects of residual pine and hardwood basal areas on selected bobwhite quail food 2 and 4 years after thinning a 35-year-old pine-hardwood stand in southeastern Arkansas. Percent covers are values calculated from their appropriate equation in Table 1.

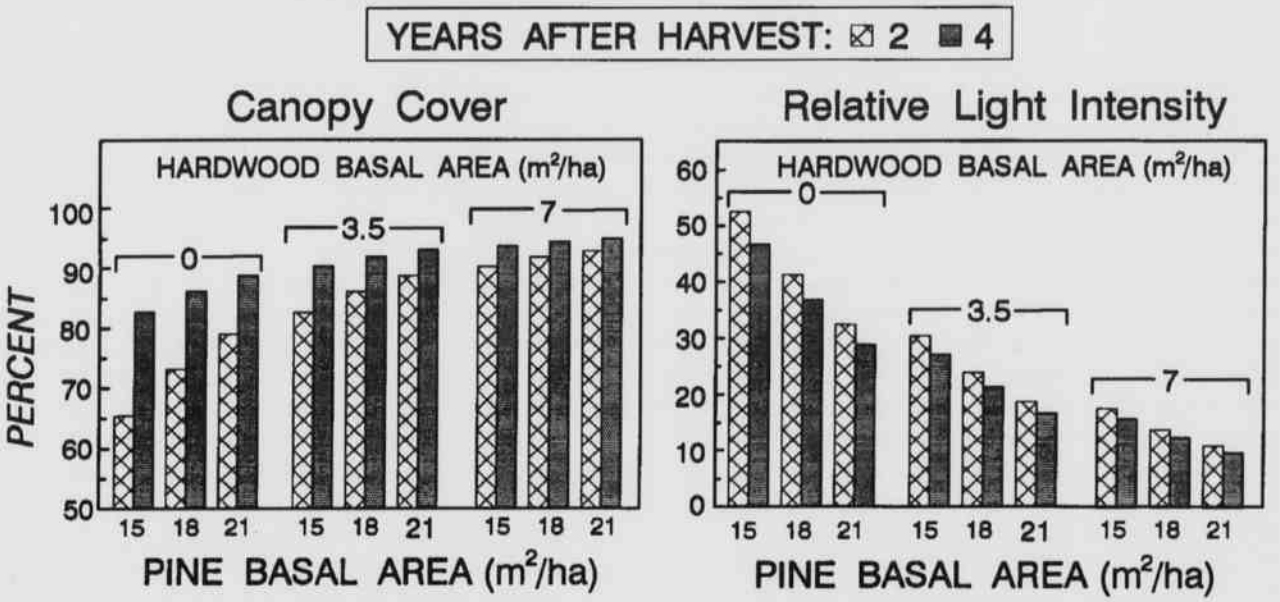

Fig. 2. Effects of residual pine and hardwood basal areas on overstory canopy cover and relative light intensity 2 and 4 years after thinning a 35-year-old pine-hardwood stand in southeastern Arkansas. Percent values were calculated from their appropriate equation in Table 1.

Discussion

Thinning is a necessary practice for improving bobwhite quail habitat on unmanaged and overstocked forested lands. Thinning reduces the overstory canopy, increases light intensity reaching the forest floor, reduces competition for nutrients and water, and releases understory vegetation for growth. For bobwhite quail, thinning requires removal of enough basal area to open up the canopy and allow increased vegetative growth in the understory while retaining some canopy to deter excessive growth of woody understory vegetation and its associated litter (Landers and Mueller, 1986). Our study demonstrated that as basal area was reduced there was a corresponding increase in understory vegetative growth and a faster rate of woody plants replacing some of the herbaceous plants utilized by bobwhite quail as food. However, some bobwhite quail plant foods were not as readily displaced by increasing woody vegetation. Therefore, we can infer that a moderate level of pine and hardwood thinning on this study site will favor bobwhite quail. Bobwhite quail are less able to forage successfully on seeds and soft mast that drop to the forest floor and become covered by litter. This situation would occur more often in stands retaining a high total basal area. Also, the ability of bobwhite quail to catch insects is inhibited by thick litter.

Operational thinnings in forested stands similar to our research area are conducted every 5 - 10 years. However, repeated thinnings on a shorter interval, less than 5 years, may be required to keep panic grass and tick trefoil at peak levels in forested stands in southeastern Arkansas. But, thinning at such a short interval may have a negative impact on American beautyberry and blackberry, as their peak coverage appears to have not been reached by the end of this study. A similar relationship between decreasing herbaceous vegetation and increasing woody plants with time has been reported elsewhere (Blair, 1971; Masters et al., 1993). Thinning and its associated disturbance was required before lespedeza, panic grass, yellow wood sorrel, and three-seeded mercury appeared in our stand because these are early successional stage plants. After initial establishment, the lack of change with time of lespedeza, yellow wood sorrel, and three-seeded mercury suggests that these plants may have been influenced more by ground disturbance from logging than by increasing canopy cover as retained trees grew.

The greater coverage of vegetation on treatment areas retaining less total basal area demonstrates that bobwhite quail habitat can be improved through thinning. All plant species in our study benefited from a reduction of the hardwood basal area with the exception of three-seeded mercury. This response of understory vegetation to thinning has been observed by others in the southeastern United States

(Masters et al., 1993; Wigley et al., 1989). The mast production of midstory hardwoods is generally low (Drake, 1991). Therefore, the removal of these hardwoods will help improve bobwhite quail habitat by increasing the light intensity reaching the forest floor and reducing the leaf litter produced. Hardwoods have been demonstrated to produce twice as much shading as pines of the same height and diameter (Tappe et al., 1993). Reduction of pine basal area increased plant coverage for some species. Panic grass and blackberry in particular appeared to have been negatively influenced by increasing amounts of pine basal area.

Our study indicates that thinning a forest stand improves bobwhite quail habitat by increasing the amount of light reaching the understory, which promotes plant growth of species utilized by bobwhite quail as food sources. However, with time, many herbaceous plants are replaced by woody plants. Hardwood retention appears to influence understory plant growth more than retained pines.

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Distribution and Status of the Ozark Shiner, *Notropis ozarcanus* Meek, in Arkansas

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Abstract

The Ozark shiner, *Notropis ozarcanus*, an endemic species of the Ozark Highlands, was studied from 1994-1995 to determine its present distribution and conservation status in Arkansas. One-hundred and four collections of fishes were made from throughout the historic range of the Ozark shiner. A total of 91 Ozark shiners was collected during the two-year study. The present state distribution is described as well as the conservation status of the Ozark shiner in Arkansas. The largest populations seem to be present in the protected Buffalo River.

Introduction

The Ozark shiner, *Notropis ozarcanus*, is a small, slender silvery minnow which occupies clear, upland streams of the Ozark Uplands of Arkansas and Missouri (Robison and Buchanan, 1988). Although once relatively commonly encountered in appropriate river systems, the federal conservation status of the Ozark shiner has recently been questioned as it appears to have declined in Missouri. Its status in Arkansas is unknown as little data exist on which to make a formal decision as to its federal protection status. A two-year status survey was initiated for the Ozark shiner in Arkansas to gather the necessary data on which to base a decision as to whether the Ozark shiner may warrant protection under the Endangered Species Act.

Materials and Methods

Field work was conducted from June, 1994 through September, 1995. A total of 104 collections of fishes was made in an effort to document the presence of the Ozark shiner in Arkansas.

Fishes were collected using standard common sense minnow seines varying in length from 4.6-6 meters and 1.8 meters in height with a bar mesh of either 0.3 or 0.6 cm. Fishes were preserved in 10 percent formalin in the field and later transferred to 50 percent isopropyl alcohol for permanent storage. Representative specimens of the Ozark shiner were preserved from certain sites where the Ozark shiner was deemed common. Associated fishes collected with Ozark shiners were also collected and enumerated.

In addition, all known contemporary and historical literature regarding the Ozark shiner was reviewed and relevant findings summarized or referenced herein. Museums known to house Ozark shiners collected in Arkansas were canvassed. Coverage includes the University of Michigan Museum of Zoology (UMMZ), Tulane University (TU), Northeast Louisiana University (NLU), Arkansas State University Museum of Zoology (ASUMZ), University of Arkansas (UA), University of Oklahoma (OU), and University of Alabama Ichthyological Collection (UAIC).

Historical Review

The Ozark shiner was originally described from 10 specimens collected from the North Fork of the White River in Baxter County, Missouri by Meek (1891). Relatively little attention has been focused on this small shiner other than notations as to its occurrence and/or abundance in various stream surveys. Even today, little is known about the biology of the Ozark shiner.

This diminuitive, slender shiner was once abundant in the White, North Fork, and Current River drainages in Missouri (Pflieger, 1971; 1975). The historic range of this species, particularly in the White River system, has been reduced by a number of impoundments such as Bull Shoals, Table Rock, Beaver, and Norfork reservoirs.

The Ozark shiner is endemic to the southern Ozark Mountains of northern Arkansas and southern Missouri with a disjunct population reported from the Illinois River (Arkansas River system) (Fig. 1) in northwestern Arkansas (Pflieger, 1971; 1975; Burr et al. 1979; Robison and Buchanan, 1988).

Type Locality.--Gilbert and Burgess (1985) erroneously gave the type locality where Meek (1891) had described the Ozark shiner as the North Fork of the White River, south of Cabool, Baxter County, Arkansas. The type locality is actually in Missouri, not Arkansas, as correctly reported by Pflieger (1971). Meek (1891) originally collected 10 specimens of the Ozark shiner from the North Fork of the

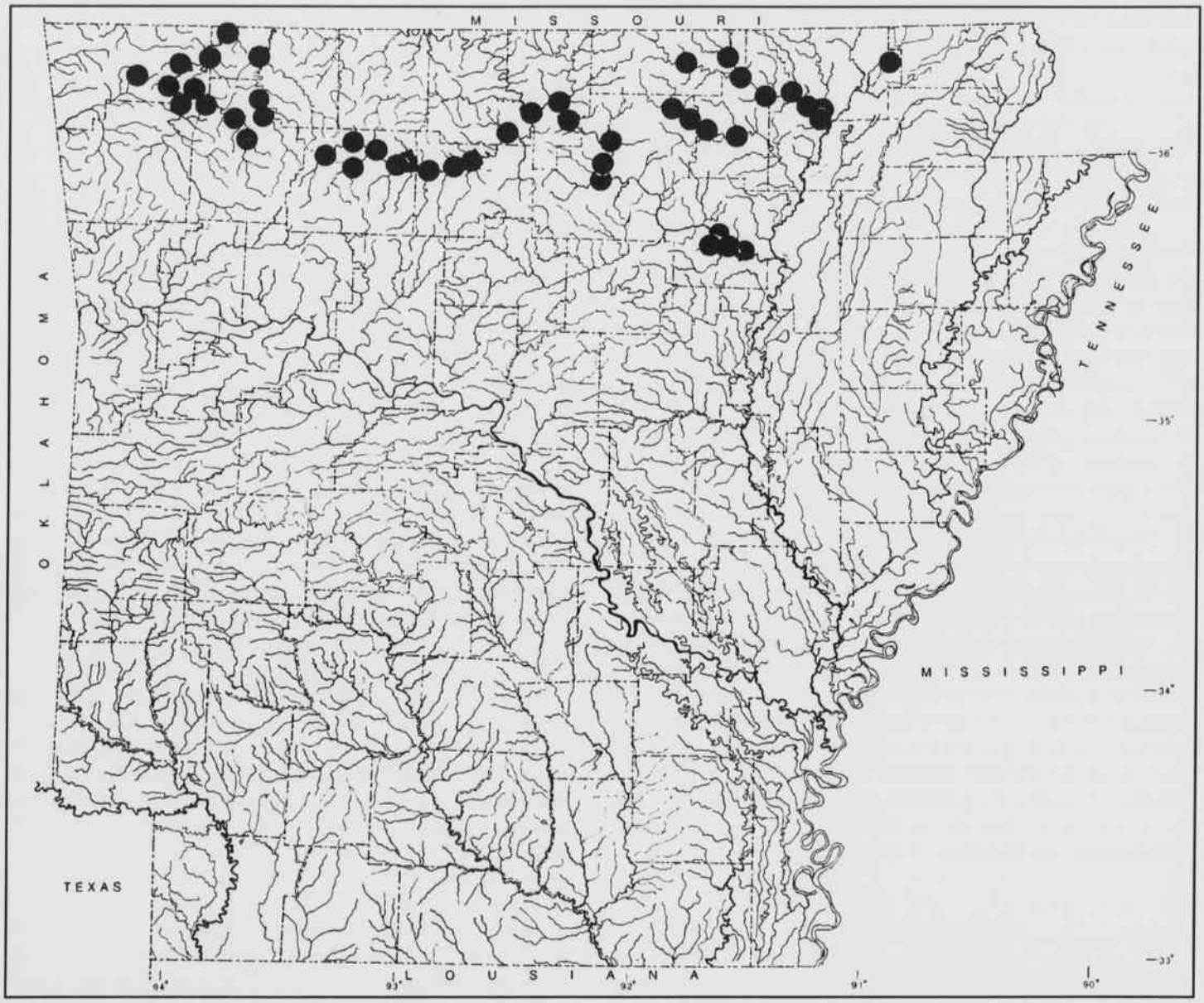

Fig. 1. Known Distribution of the Ozark Shiner, *Notropis ozarcanus* Meek, in Arkansas.

White River. He presented the exact location on p. 115 of his 1891 paper and later repeated this in his "catalog" (Meek, 1894a:242).

Habitat and Life History Aspects

Black (1940) found *N. ozarcanus* in large creeks and small to medium-sized rivers where the water was clear and cool to cold. Cashner (1967) reported this species in clear deep water over sand and gravel bottoms. Guidroz (1975) also collected *N. ozarcanus* only in deep pools, noting the difficulty in collection of this species. Pflieger (1971) stated the Ozark shiner inhabited large, clear streams with high gradients and permanent flow in Missouri, occurring most abundantly near riffles in a slight-to-moderate current over a firm, silt-free bottom. Gilbert and Burgess (1985) reported that this shiner inhabited medium to large, clean streams with high gradient and permanent, strong flow. They said it was most common near riffles in slight to moderate current over firm, silt-free bottoms. Robison and Buchanan (1988) presented the habitat of the Ozark shiner as high-gradient stream sections below riffles in slight to moderate current in large streams and rivers.

In this study the Ozark shiner seemed to be a midwater schooling species which preferred high-gradient stream sections of clear, upland medium size to large rivers, usually occurring in areas just below riffles in slight to moderate current over gravel, cobble, or sand bottoms. There does not seem to be an affinity of the Ozark shiner for aquatic vegetation such as *Justicia americana* which is common within its range.

The Buffalo River in the Springfield Plateau near St. Joe, Arkansas, where the Ozark shiner was commonly collected, was characterized physicochemically by water temperatures ranging annually from 3.0°C degrees in winter months to 31°C in the summer, dissolved oxygen values of 6.8-13.8 mg/l, pH of 6.95-8.84, BOD of 0.0-4.3 mg/l, conductivity of 114-249 micromhos, chloride of 1.0-9.0 mg/l, alkalinity of 52-144 mg/l; discharge of 27-25,500 cfs, and turbidity levels of generally less than 1.0 NTU.

Eastward on the Salem Plateau in the Strawberry River habitat frequented by the Ozark shiner was characterized physicochemically by temperatures ranging annually from 1°C in winter months to 32°C in the summer, dissolved oxygen values of 5.9-14.0 mg/l, pH of 7.12-8.60, BOD of 0.1-3.9 mg/l, chloride of 1.0-6.0 mg/l, alkalinity of 40-238 mg/l; discharge of 58-11,200 cfs, and turbidity levels of 1.0-280 NTU.

These data presented are not intended to indicate parameter limits of the Ozark shiner, but rather to simply characterize physicochemically stream regions where the Ozark shiner seems to be moderately abundant.

Adults of *N. ozarcanus* in spawning condition have been collected in Missouri and Arkansas from late May to late August, indicating a long spawning season (Pflieger, 1975; Robison and Buchanan, 1988). Adult tubercled males in darkened breeding coloration were collected on 23 June 1995 in the Buffalo River. Little else is known about the life history of this enigmatic species.

Distribution

The following is a presentation of the distribution of the Ozark shiner by river system or main river area. Comments are made concerning its historical presence, plus the findings of this survey. Analysis of the status of the Ozark shiner in the individual river systems follows in a separate section.

White River and Smaller Tributaries.--In a pre-impoundment survey of the upper White River (Beaver Lake drainage), Keith (1964) reported *Notropis ozarcanus* probably "failed to show its true abundance" due to the fortune of his collecting methods which included electro-seining. He usually found only one or two specimens present; however, along a certain stretch of War Eagle Creek, the shiner was collected in larger numbers. At two stations on the War Eagle, Numbers 7 and 8, Keith collected 81 and 37 individuals, respectively. Keith (loc. cit.) noted that the Ozark shiner occurred in pools of upstream sections with 1.5-6.1 m/km gradient, whereas it was rare in downstream sections where gradients were less than 1.5 m/km. He did not find this shiner in smaller tributaries to the White River. Brown et al. (1967) surveyed the fishes of the cold tailwaters of three reservoirs including Beaver Reservoir, Bull Shoals Reservoir, and Norfork Reservoir. No Ozark shiners were found in the cold tailwaters below any of the three reservoirs.

Pflieger (1971) reported the Ozark shiner to be common in the North Fork of the White River in Missouri. It was formerly abundant in the section of the White River presently inundated by Bull Shoals and Table Rock reservoirs. By 1992 however, Pflieger (*in litt.* 1993) could collect only three individuals of *N. ozarcanus* in a survey of the Missouri portion of the White River system which caused him to reassess the present status of the Ozark shiner in that system as "on the verge of extinction."

Recent collecting in the upper White River system (1993-94) by the writer while surveying for another upland species, the longnose darter (*Percina nasuta*), did not reveal any individuals of the Ozark shiner in this area, although numerous collections were made.

Matthews and Harp (1974) reported a single specimen of the Ozark shiner from Piney Creek, near its confluence with the White River. In almost 30 years of collecting from the Piney Creek system, no additional specimens of Ozark shiners have been taken (W. J. Matthews, pers. comm.).

The Ozark shiner is apparently absent from Crooked Creek, one of the premiere smallmouth bass fishing streams in Arkansas, as collections during this survey did not produce a single specimen, nor have periodic collections from Crooked Creek by the writer during the past 15 years. In addition, no other museum records are available for this species from Crooked Creek despite collecting by a number of ichthyologists.

A survey of the fishes of Sylamore Creek, another direct tributary of the White River near Mountain View, Arkansas, by Frazier and Beadles (1977) failed to find the Ozark shiner within the system.

The farthest downstream collection of the Ozark shiner in the White River system is near Batesville, Arkansas. Meek (1894b) collected *N. ozarcanus* from the lower White River tributaries of Salado Creek and Caney Creek near Batesville. In addition, museum records are available from Northeast Louisiana University from the main channel White River from 1967-1976.

Kings River System.--Black (1940) made the largest collection of *N. ozarcanus* (UMMZ 123376 - 157 specimens) ever made from the Kings River, 4.8 km east of Alabam in

Madison County just below the inlet of a sizable cold stream from Denny's Cave. A quarter of a century later, Cashner (1967) collected just one specimen from this river. Seven specimens taken during the present survey re-established the Ozark shiner as a resident and were the first documentation of the species in this system since 1967. The seven specimens came from approximately 5.63 km north of Kingston, Arkansas on St. Hwy. 21 (Sec. 33, T17N, R24W) on 24 June 1995. A total of nine collections was made from this system with only one collection yielding Ozark shiners.

Buffalo River System.--Black (1940) recorded 26 species of fishes from six localities including 10 specimens of the Ozark shiner (UMMZ 123535 eight specimens; UMMZ 127728 - one specimen; UMMZ 169902 - one specimen). Using electroshocking, Cashner (1967) collected 375 specimens of Ozark shiners from six locations on the Buffalo River. Guidroz (1975) surveyed the fishes of this river over 20 years ago in a two-year study from 1971 to 1973. He reported 220 specimens of *N. ozarcanus* from 10 locations in this system. Guidroz (1975) reported *N. ozarcanus* to be rather common, but noted that its preference for deep pools made collecting difficult.

In a longitudinal distribution survey of the Buffalo River, Cashner and Brown (1977) documented 59 species of fishes, but did not comment specifically on *N. ozarcanus*; however, they noted in a table that this species occurred virtually the entire length of the main river.

Based on previous Arkansas collections now housed in the Tulane University and Northeast Louisiana University fish collections (many of which were over 20 years old), Robison and Buchanan (1988) suggested that the Buffalo River may hold the best populations of this enigmatic shiner due to its relatively pristine conditions. Recent collections from the Buffalo River for a three-year period (1990-1992) by Dr. James Johnson (University of Arkansas) and his students revealed a total of 72 specimens of *N. ozarcanus* from six locations (Dr. James Johnson, pers. comm.).

Collections made in May-July 1995 from the Buffalo River by the writer re-established the Ozark shiner as a rather widespread, somewhat common fish species of the Buffalo River. The Ozark shiner was found at seven localities in the system from the Ponca low-water bridge in the headwaters in Newton County downstream to St. Hwy. 14 in Marion County. It was most abundant through the Mt. Hersey and Woolum areas. A total of 63 specimens was collected from the Buffalo River during this most recent survey.

The specific collecting localities, dates, and number of specimens collected were 1) Buffalo River at St. Hwy. 74 at Ponca low-water bridge (Sec. 30, T16N, R22W). Newton County. 25 June 1995. Five specimens. 2) Buffalo River at Steel Creek Recreation Area (Sec. 17, T16N, R22W). Newton County. 26 May 1995. Eight specimens. 3) Buffalo River at U. S. Hwy. 65 (Sec. 36, T16N, R17W). Searcy County. 23 June 1995. Eleven specimens. 4) Buffalo River at Woolum Access (Sec. 3, T15N, R18W). Searcy County. 23 June 1995. Sixteen specimens. 5) Buffalo River at Mt. Hersey Access (Sec. 31, T16N, R18W). Searcy County. 25 June 1995. Twelve specimens. 6) Buffalo River at Carver Access (Sec. 6, T15N, R19W). Newton County. 8 July 1995. Five specimens. 7) Buffalo River at St. Hwy. 14 (Sec. 33, T17N, R15W). Marion County. 23 June 1995. Six specimens.

Strawberry River System.--Meek (1894b) first collected *Notropis ozarcanus* in the Strawberry River at Smithville, Arkansas, noting that the species was scarce. A single lot (USNM 59288) collected by Meek in 1907 is housed in the United States National Museum. Robison and Beadles (1974) later surveyed the fishes of the Strawberry River system and reported *N. ozarcanus* as common, but not found in large numbers. They reported it from high gradient stream sections with clear substrates. Hilburn (1987) established 22 stations on the Strawberry River and collected 15,746 fishes comprising 72 species, including 135 specimens of *N. ozarcanus.*

Fifteen collections made from the Strawberry River system during this study yielded only 18 specimens from just two sites in Sharp County: U. S. Hwy. 167 north of Evening Shade, AR. (29 July 1994 - three specimens; 27 July 1995 - 14 specimens) and St. Hwy. 58 north of Poughkeepsie, AR. (6 October 1994 - one specimen) (Fig. 2).

Spring River System.--Fowler and Harp (1974) studied Jane's Creek, a tributary of the Spring River, and reported five *N. ozarcanus* at the mouth of Jane's Creek and Spring River. This station consisted of small, deep pools with submerged logs and undercut banks but no aquatic vascular plants.

Winters (1985) later surveyed the fishes of the entire Spring River system and reported 94 species of fishes including *Notropis ozarcanus.* He collected 84 Ozark shiners during his survey from 10 different localities. While the Ozark shiner was not commonly encountered in his survey, he did note that, interestingly, one large series of 61 specimens (NLU 43535) was collected in 1979 from the Spring River, approximately eight km upstream of Ravenden Access during flooded conditions (S. Winters, pers. comm.), and that this shiner generally preferred moderate currents over gravelly sand bottoms.

Collections during this survey revealed the Ozark shiner to be rare in the Spring River, as only three specimens were taken in 12 collections from seven localities throughout the system. These were collected from the Spring River, approximately 1.6 km south of Ravenden, Lawrence County, AR (Sec. 12, T18N, R3W) on 28 May 1995.

Eleven Point River System.--Johnson and Beadles (1977) reported *N. ozarcanus* as rare within the Eleven Point River system in Arkansas. They found it in quiet pools of the main

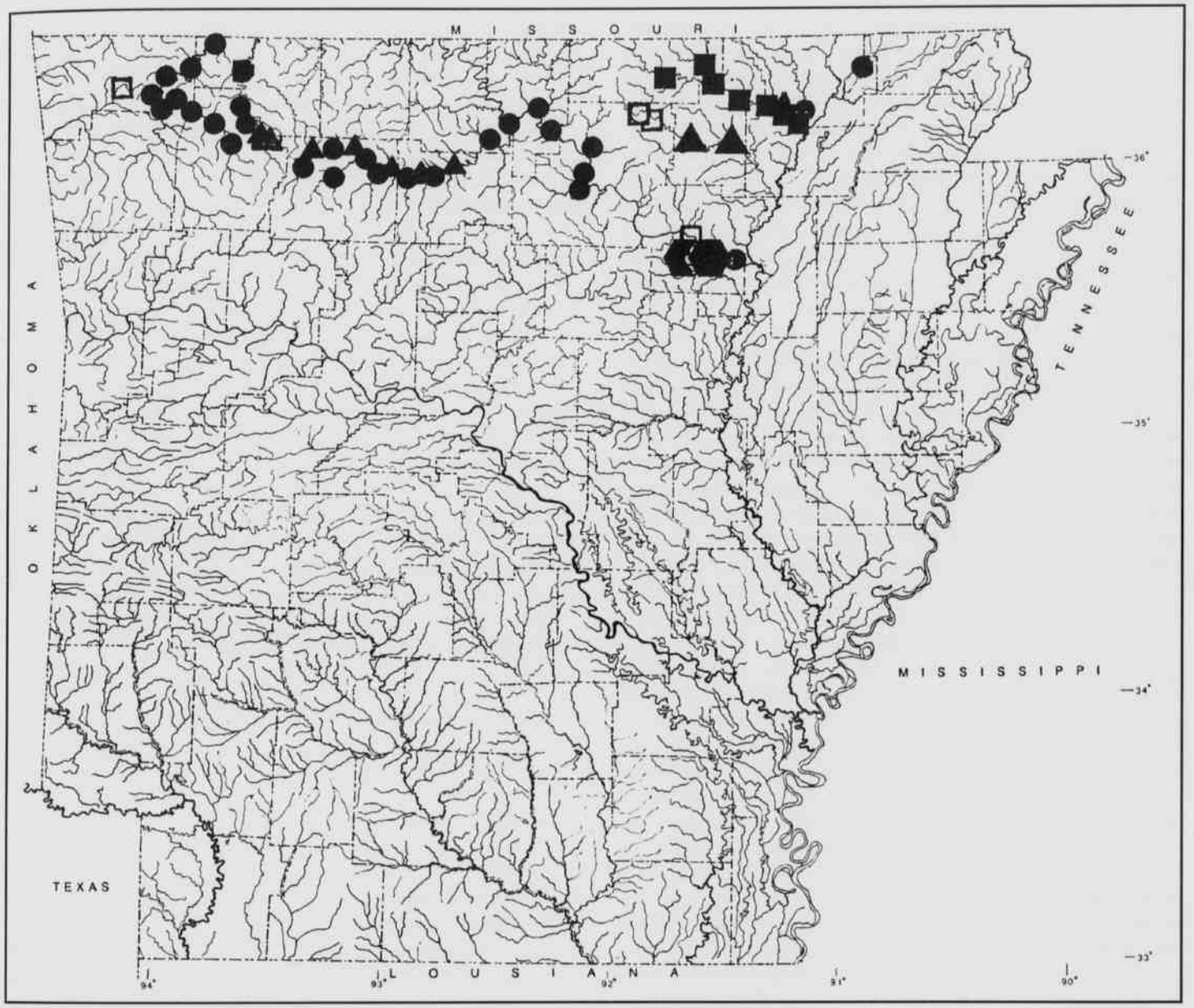

Fig. 2. Distribution of the Ozark Shiner, *Notropis ozarcanus* Meek, by Chronological Date Collected: 1881 = ⬣; 1939-1969 = ●; 1970-1978 = □; 1979-1989 = ■; 1990-1995 = ▲.

river .

Although 10 collections were made from the Arkansas portion of the Eleven Point River system, no specimens of the Ozark shiner were taken during this survey.

Current River System.--Green and Beadles (1974) reported the Ozark shiner as uncommon in both upland and lowland habitats. Pflieger (1971) reported this shiner to be common in the Missouri portion of the Current River. Pflieger (*in litt.* 1993) collected 43 specimens at seven collection sites in the Current River drainage, which prompted him to consider the *N. ozarcanus* population to be relatively stable in the Missouri portion of the drainage.

No specimens of *N. ozarcanus* were collected during this survey in the Arkansas portion of the drainage. Five collections were made in the Arkansas portion of the Current River system from three localities.

Black River and Smaller Tributaries.--Neither Bounds and Beadles (1975) nor Bounds (1977) who surveyed Fourche Creek, a Black River tributary, collected any Ozark shiners from this creek. Yeager and Beadles (1976) surveyed Cane Creek, another Black River tributary, but also failed to find Ozark shiners.

This survey failed to find the Ozark shiner in the Black River in Arkansas as did Pflieger (*in litt.* 1993) in the Missouri portion of the drainage. The river is quite large in the Arkansas portion, and suitable upland habitat for the Ozark shiner probably does not exist in the state.

St. Francis River System.--The St. Francis River has been heavily altered through land-use perturbations in the Arkansas portion of its drainage. Harvill (1989) earlier surveyed the fishes of the Arkansas portion of the St. Francis drainage and did not collect *N. ozarcanus.* No attempt was made to seine this drainage during this survey, as suitable habitat for the Ozark shiner does not occur in this system in Arkansas today.

Arkansas River System.--Burr et al. (1979) reported 17 specimens of the Ozark shiner from a single collection from Osage Creek, a tributary to the Illinois River, about two km south of Logan, Benton County, Arkansas. This is the only record of the Ozark shiner to date from the Arkansas River system. Ten recent collections by Dr. James Johnson (pers. comm.) from the upper Illinois River did not yield a single specimen of *N. ozarcanus.* No new collections were made in Osage Creek during this study.

Conservation Status

Historical Conservation Status.--Black (1940) made an interesting observation with regard to *Notropis ozarcanus* over 50 years ago. He noted that while this shiner is locally common, it is frequently absent from apparently favorable localities. Cloutman and Olmsted (1976) noted that *N. ozarcanus* was "rare" in their survey of the fishes of Washington County, AR, as they did not collect a single individual. In fact, they observed the Ozark shiner had not been collected in Washington County since Keith's (1964) preimpoundment collections, although they speculated it was probably still present in War Eagle Creek.

In independent assessments of the threatened fishes of Arkansas, neither Buchanan (1974) nor Robison (1974) included the Ozark shiner in their publications. Gilbert and Burgess (1985) reported *N. ozarcanus* was formerly common, but now has been eliminated from many impounded areas. Robison and Buchanan (1988) did not list *Notropis ozarcanus* in their discussion of rare and endangered fishes in Arkansas.

In a 1992 survey for the Ozark shiner in Missouri, Pflieger (pers. comm.) captured only three specimens of *Notropis ozarcanus* in the White River, because much of this area has been inundated by reservoirs. Such is the case in Arkansas as many of the White River localities have also been inundated by reservoirs. Habitat loss is one of the greatest causes of the declines in populations of native fishes in North America (Williams et al., 1989). Widespread reservoir construction and decline in water quality have severely altered most of North America's clean, free-flowing riverine habitat (Benke, 1990).

Present Conservation Status.--The state of Arkansas presently has no official state list of threatened or endangered wildlife or plants. Instead, protection is afforded by the Arkansas Game and Fish Commission primarily to federally threatened species.

A total of 104 collections of fishes was made during this study within the historical distribution of the Ozark shiner. From these 104 collections only 91 specimens of Ozark shiners were captured (Table 1). After careful review of all of the major holdings of the Ozark shiner available, two years of intensive field work collecting Ozark shiners, review of all pertinent literature, and discussions with virtually all of the major collectors of Ozark shiners in Arkansas, it is readily apparent that the Ozark shiner has declined in abundance throughout its historical range in Arkansas (Map 2).

Table 2 provides a quick view of the decline in abundance of the Ozark shiner in Arkansas by decade. While certainly not definitive, Table 2 shows the Ozark shiner seeming to decline in the decade of the 1980s and continuing into the 1990s. When the number of *N. ozarcanus* per collection is viewed, the decline of this species may have occurred much earlier than the 1980s. A closer inspection of the 1146 museum specimens of *Notropis ozarcanus* by river system reveals that 51.2 percent (587 individuals) of the specimens were collected from a single river system, the Buffalo River (Table 3).

Table 1. Collecting Localities, Number of Collections, and Numbers of Ozark Shiners Collected in Arkansas in 1994-1995.

Locality (River System)	No. of Collections	No. Ozark Shiners
1. White River (mainstream)	11	0
2. White River (smaller tribs)	10	0
3. War Eagle Creek	3	0
4. Kings River	9	7
5. Buffalo River	17	63
6. North Fork	2	0
7. Crooked Creek	6	0
8. Strawberry River	15	18
9. Spring River	12	3
10. Eleven Point River	10	0
11. Current River	5	0
12. Black River	4	0
TOTAL	104	91

While data gathered from this study indicate that overall there seems to be a decline in the populations of the Ozark shiner in Arkansas, such is not typically the case in the Buffalo River. This river, where 67 of the 91 specimens of the Ozark shiner were collected during this study, seems to continue to support a rather large and widespread population of the Ozark shiner. However, this overall reduction in range and abundance in Arkansas necessitates a re-evaluation of the conservation status of the Ozark shiner.

Table 2. Number of Ozark Shiners Collected By Year, Number of Collections of Ozark Shiners By Year, and Mean Number Per Collection By Year.

Years	No. Ozark Shiners	No. Collections	Mean No. Per Collection
1938-1939	242	13	18.6
1950-1959	121	3	40.3
1960-1969	143	58	2.5
1970-1979	426	48	8.9
1980-1989	13	4	3.3
1990-1995	201	32	6.3
Totals	1146	158	

Table 3. Collections of the Ozark Shiner By River System.

River System	No. Ozark Shiners	Percentage	Collections
White River	173	15.1	42
Kings River	198*	17.3	8
Buffalo River	587	51.2	81
Strawberry River	90	7.9	12
Spring River	93	8.1	13
Eleven Point River	4	0.3	1
Current River	1	0.1	1
Total	1146	100.0	158

*One collected by J. D. Black (UMMZ 123376) accounted for 157 specimens of this total.

Reasons for this decline seem to be multiple and complex. Destruction and modification of habitat from impoundments with concomitant cold water release remains a large part of the problem for the Ozark shiner. The Ozark shiner has disappeared from a number of stream reaches in the White River which are now impounded and also from downstream reaches where cold water releases influence areas many kilometers downstream from reservoirs (Fig. 2). Reservoirs also effectively eliminate migration by obligate stream fishes from one tributary to another, precluding natural colonization of potentially suitable streams. Increases in turbidity and siltation have also occurred in the upland streams inhabited by the Ozark shiner as poor land practices such as road building, farming, clearing of land for pasture, clearcutting, destruction of riparian buffer strips and other human perturbations continue in these watersheds. Other possible reasons for decline of the Ozark shiner include gravel removal operations in many Arkansas streams (Filipek and Oliver, 1994), nutrient enrichment from the enormous increase in poultry and swine operations, and human population increases.

During this two-year study the continued presence of the Ozark shiner was documented in several of the river systems in Arkansas from which it was collected historically, including the Buffalo, Spring, and Strawberry river systems (Fig. 2). No specimens were collected from the upper White River above or below Beaver Reservoir, War Eagle Creek, North Fork of the White River below Lake Norfork, Eleven Point River, or the Current River. In addition to these areas where the Ozark shiner had been collected historically, collections were made in several stream systems not previously known to contain Ozark shiners. No new populations were discovered.

Thus, after carefully reviewing the collection records of the Ozark shiner from the University of Michigan, Northeast Louisiana University, Tulane University, Arkansas State University, University of Arkansas, and the University of Oklahoma, and two years of field work, the Ozark shiner is not herein recommended for official federally threatened status at this time. Rather, this small silvery cyprinid species should be accorded a status of "Special Concern" and a program be initiated to monitor its continued existence in northern Arkansas. The apparent small populations and low densities make it imperative that a careful watch on this species be maintained in the future.

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A Hydrogeological and Hydrochemical Connection Between the Decatur City Spring and Crystal Lake, Benton County, Arkansas

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Abstract

Arkansas is ranked nationally in the production of broilers, laying hens, turkey, swine and beef cattle. These animals produce large volumes of waste, which are spread on pasture land as a method of disposal, as well as a source of fertilizer, resulting in nonpoint source contamination of surface water and ground water. One area of concern includes the Decatur City Spring, which provides municipal water for the city of Decatur. A total of eight sites in the surrounding area were monitored routinely for water quality parameters, including pH, specific conductance, and nitrate-nitrogen. Water temperature and spring and lake stage were also recorded. Crystal Lake (site 7), an impoundment of Wolf Creek (site 4) is south and upstream from the Decatur City Spring (site 3). It has been proposed that the city spring and lake are hydrogeologically connected. Additionally, there are two springs, (sites 5 and 6) both northwest and downstream of the lake, below the dam, that provide most of the flow to Wolf Creek. Spring site 1 is downstream from Decatur City Spring on Wolf Creek. Results indicate relatively low, but consistent nitrate concentrations for sites 7 (0.7-1.4 mg/L), 5 (0.4-1.0 mg/L) and 6 (0.2-0.6 mg/L), which are the lake and two springs below it, respectively. These consistent concentrations, as well as the similar periodicities, suggest an association between these three sites. Higher nitrate concentrations are exhibited for sites 3 (2.4-3.0 mg/L) and 1 (2.4-2.9 mg/L), which are the city spring and the spring north of it. There is also correlation in the periodicity of these two sites indicating a relationship between them. Based on similar fluctuations in the hydrochemical data, it can be concluded that Crystal Lake and Decatur Spring are hydrogeologically related. Water flows from Crystal Lake to the two springs below the dam. These springs feed Wolf Creek which is then connected to Decatur Spring via a losing segment just above the spring, hydrogeologically connecting Decatur Spring to Crystal Lake.

Introduction

Agriculture is considered the primary source of pollution for surface water and ground water (Novotny and Chesters, 1981), but it is necessary to provide food and sustain the economy. The degradation of ground water quality in agricultural areas is ubiquitous, but the problem becomes more severe where natural mechanisms to purify the contaminants are lacking. Karst regions are particularly susceptible to pollution problems because there is rapid infiltration of surface water to ground water through the highly permeable limestone. The surface water may contain contaminants such as agricultural byproducts, including animal wastes and fertilizers, which do not have sufficient time to chemically or biochemically degrade because there is less water to host rock contact (Novotny and Chesters, 1981). In these areas ground water may be the source of water for homes and rural communities.

Karst terrain comprises forty percent of the land area east of Tulsa, Oklahoma (White et. al., 1995), and fifteen percent of the United States (Robinson, 1982), including major agricultural states such as Alabama, Arkansas, Florida, Kentucky, Missouri and Virginia. Arkansas is ranked nationally in the production of broilers (#1), laying hens (#8), turkeys (#3), swine (#15), and beef cattle (#18) (Cooperative Extension Service, 1994; Arkansas Agricultural Statistics, 1994). These animals produce large volumes of waste which are spread on pasture land as a method of disposal and a source of nutrients for crops. Northwest Arkansas also has extensive carbonate terrain with a limestone that is readily soluble and extensively fractured, and includes many caves, sinkholes and solution channels that make the aquifer particularly susceptible to contamination (Leidy, 1989).

Nonpoint source contamination of surface and ground water in western Arkansas has resulted from the waste spreading operations (Adamski, 1987). The main contaminants associated with the wastes are nitrate-nitrogen, phosphorous and bacteria. Novotny and Chesters (1981) define nonpoint pollution as highly dynamic in random intermittent intervals with the most severe impact during or following a storm event, and the point of entry often cannot be identified or defined. In order to protect the ground water resources, it is necessary to identify the areas and mecha-

A Hydrogeological and Hydrochemical Connection Between the Decatur City Spring and Crystal Lake, Benton County, Arkansas

nisms by which pollutants can enter the ground water flow system and to develop reliable diagrams of transport of contamination and flow paths within the system (Freeze and Cherry, 1979).

Location

The study area is located near the City of Decatur, Benton County, Arkansas (Fig. 1). The site was chosen because: (1) The area is underlain by carbonate rock which may be susceptible to contamination because of solution channels, secondary fractures, as well as the rapid underground movement of water. (2) The area is headquarters to a growing poultry industry which participates in poultry waste spreading operations in surrounding fields.

The City of Decatur obtains its municipal water supply from a spring about 1.5 miles north of town (Figure 2). The spring is approximately 1500 feet east of Wolf Creek and approximately 1 mile north of Crystal Lake, an impoundment of Wolf Creek. It has been reported that there is a positive correlation between spring level and water level at Crystal Lake (pers. comm., Rick McClain, Water Superintendent, City of Decatur, 1995).

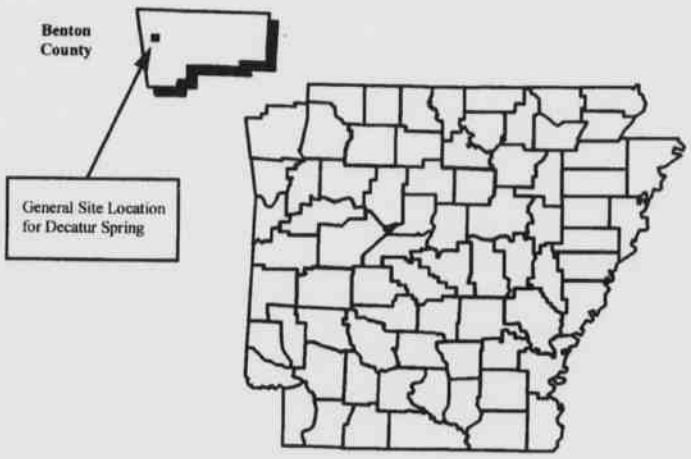

Fig. 1. Location of study area

Purpose and Objectives

The primary objective of this research was to determine if there is a hydrogeological and hydrochemical connection between the Decatur City Spring and Crystal Lake, Benton County Arkansas. Secondary objectives were (1) to determine the quality of ground water in the area by analyzing samples from eight sites (Fig. 2) in the study area once a week for ten weeks, and (2) to identify current and potential nonpoint source contributors to contamination if pollution is detected.

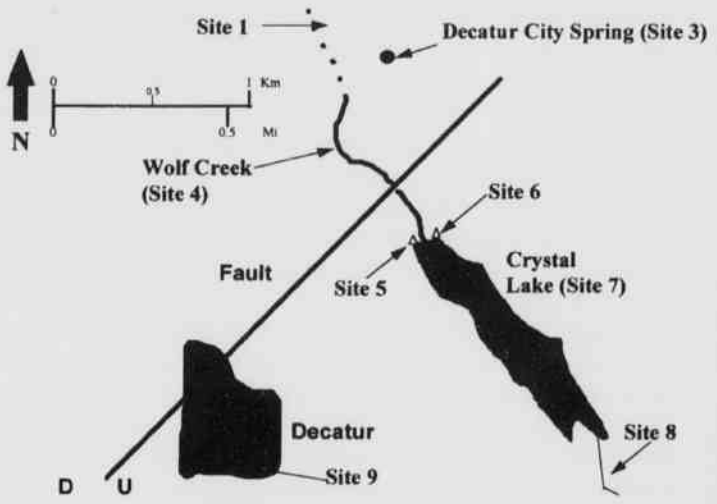

Fig. 2. Location of sites in the study area (modified from Monk, 1997)

Site Number	Site name
1	Spring north of the Decatur City Spring
2	Dried up before testing could occur
3	Decatur City Spring
4	Wolf Creek
5	Spring downstream from Crystal Lake
6	Spring downstream form Crystal Lake
7	Crystal Lake
8	Spring upstream from Crystal Lake
9	Corner Spring

Geology

The study area lies along the southern flank of the Ozark Dome and on the Springfield Plateau. Exposed rocks are primarily the St. Joe Formation overlain by the Boone Formation, both of the Mississippian system. In several areas the Upper Devonian Chattanooga Shale is exposed due to undercutting of streams, erosion and dissolution of limestone (Monk, 1997). Rocks are essentially undeformed with only one major mapped fault, Decatur Fault, trending northeast in the area. Decatur Spring is located on the downthrown block of the Decatur Fault and Crystal Lake is

on the upthrown block (Monk 1997). There is also an observed northwest trending lineament, that cuts through the location of Decatur Spring and continues southeast across and normal to the Decatur Fault, and through Crystal Lake. There are also many surface fractures and joints, which act as recharge mechanisms for precipitation entering the aquifer. All the above-mentioned structural features may control the movement of ground water, acting both as conduits and as barriers (Monk, 1997). Their identification is critical in identifying contamination sources and modeling ground water flow.

Upper Devonian Chattanooga Shale.--The Chattanooga is usually a black, carbonaceous, fissile shale, and acts as an effective regional confining unit. It is clayey and generally ranges from 10 to 75 feet thick, with joints trending northeast and northwest. There are areas of bright yellow pyrite present locally. The Chattanooga unconformably overlies Ordovician or Devonian Strata (Leidy, 1989).

Mississippian St. Joe Formation.--The St. Joe Formation is characterized mostly by lightgray to reddish brown, fossiliferous, chert-free limestone that rests unconformably over the Chattanooga Shale. The limestone shows occasional grading from fine to coarse grains, but it occurs in single beds that are local to a section and cannot be correlated from section to section (Shanks, 1976). According to Shelby (1986) the St. Joe carbonates can be divided into four facies: bioclastic lime mudstone, bioclastic lime wakestone, bioclastic lime grainstone, and bioclastic lime packstone. The St. Joe Formation shows variability in thickness in north Arkansas, ranging from 6 to 84 feet with an average thickness of 45 feet (Shanks, 1976). In Northwestern Arkansas, the St. Joe can be subdivided into four members. In ascending order these include the Bachelor, Compton, Northview, and Pierson. These subdivisions are often hard to differentiate in their lithic zones, but can all be identified in the section exposed below the dam at Crystal Lake. Sites 5 and 6, the springs below Crystal Lake discharge from the St. Joe Limestone and appear to be controlled by the Northview Shale, which acts as a local lower confining unit for these springs (Monk, 1997). There are many joints in this unit trending both northeast and northwest, which may act as structural controls to flow.

Boone Formation.--The Boone Formation lies conformably over the St. Joe Formation, and the boundary is marked by a thin calcareous shale unit (Manger and Shanks, 1977). The thickness of the Boone is variable due to active erosion (Shelby, 1986) and ranges from 50 feet to 375 feet (Leidy, 1989).

The Boone Formation is divided informally into two segments designated as upper and lower, primarily differentiated by the type of chert development with the contact being a conformable one (Shelby, 1986). Dark colored chert, formed at or near the time of deposition, comprises the Lower Boone, while the Upper Boone contains light-colored, later diagenetic chert formed by replacement processes (silica replacing carbonate sediment) after deposition (Shelby, 1986).

The Boone formation is important to this study because the Decatur City Spring flows out of the Upper Boone.

Materials and Methods

The following chemical parameters were evaluated for all water samples:

Temperature °C pH Conductivity µS/cm
Nitrate-N mg/L Alkalinity mg/L Chloride mg/L

Temperature, conductivity, pH and alkalinity analyses were done in situ.

Samples were collected in 500 mL plastic bottles, placed in coolers, and brought to the laboratory for chemical analyses. The sample bottles were cleaned in the laboratory prior to collection and were then rinsed three times at each site, before each sample was taken. The methods of analysis for each parameter are as follows:

Temperature: Temperature was measured in the field with a digital conductivity meter, which contained an internal thermometer. The accuracy was +/- 0.1° C.

pH: pH was measured in the field using an Orion digital pH meter with an accuracy of 0.01 pH units. The meter was calibrated with pH 4 and pH 10 buffer solutions prior to each day's use.

Conductivity: Conductivity was measured in the field using a digital conductivity meter with an accuracy of +/- 5%. The meter was calibrated with a standard solution prior to each field visit.

Nitrates: Nitrate-N concentrations were determined in the lab within the recommended 24 hour holding period (U.S. EPA, 1976). Samples were first filtered using 45 µm media pads. The samples were then analyzed using the Hach Company colorimetric cadmium reduction method utilizing NitraVer 5 nitrate reagent. Twenty-five milliliters of sample were pipetted into each of two 1/2 inch spectrophotometric cells. One cell, the sample blank, was placed into Hach DR/2000 direct reading spectrophotometer set at 500 nm. NitraVer 5 reagent powder was added to the second cell. The cell was shaken for one minute and allowed to stand for 5 to 14 minutes before inserting it into the spectrophotometer to determine the transmittance. The accuracy of the nitrate test is determined to be +/- 0.5 mg/L.

Alkalinity: Alkalinity concentrations were determined in the field. Fifty milliliters of sample were pipetted into a beaker. The sample was brought to 100 mL by the addition of deionized water. Phenolphthalein was added to the solution. All samples remained colorless at this point indicating the phenolphthalein alkalinity was zero. One bromcresol green-methyl red indicator powder pillow was added to the mixture, turning it green. The solution was titrated with 0.02 N standard sulfuric acid until the solution turned a light blue-gray. The accuracy of the alkalinity test is determined to be +/- 1 mg/L.

Chloride: Chloride concentrations were determined utilizing the Hach Company mercuric nitrate methods (Hach Company, 1995) using mercuric nitrate standard solution (0.0141 N) and dipenylcarbazone reagent powder. The reagent powder was added to 100 mL of sample and mixed with a magnetic stirrer. The mixture was then titrated with 0.0141 N mercuric nitrate standard solution until the color changed from yellow to a light pink. The mL of titrant was multiplied by 0.10 to determine the chloride concentration in mg/L. The accuracy of the chloride test is determined to be +/- 1 mg/L.

Results and Discussion

Nitrates.--Nitrate-N concentrations (Fig. 3) occur in ground water primarily due to agricultural processes such as waste spreading and application of fertilizers (Hem,1992). Where concentrations are elevated, adequate denitrification has not occurred. The background nitrate concentration in Northwest Arkansas is 1 mg/L or less (Adamski, 1996).

In the study area, Corner Spring (site 9) had the highest nitrate concentrations probably due to agricultural activity in the surrounding fields. The concentrations exhibited at this site are somewhat unique to the rest of the study area. Corner Spring discharges west of the Decatur Fault where the outflow passes across the Fault zone about two miles southwest of Wolf Creek. A portion of this higher nitrate water may be infiltrating into the ground water along the fault. It would then follow the regional gradient to the northeast and may represent one source of higher nitrate water entering Wolf Creek in the area below the Crystal Lake dam.

The spring (site 8) upstream from Crystal Lake is probably connected to the lake (site 7), as supported by the correlation coefficient of 0.76. The spring has a higher average

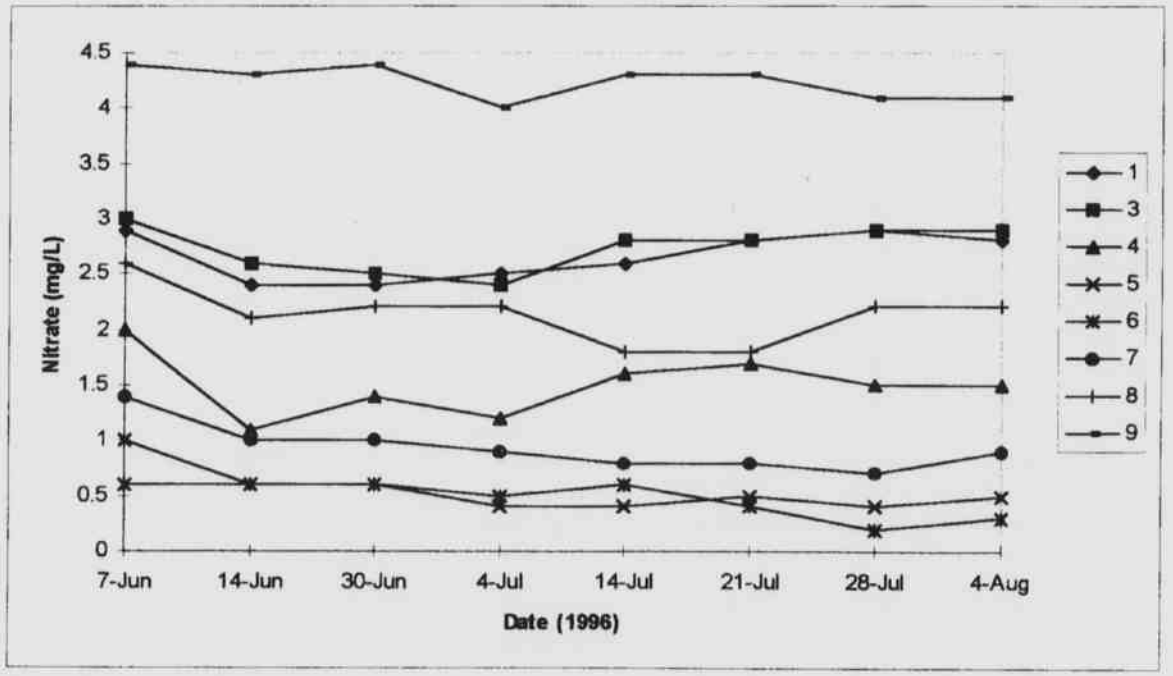

Fig. 3. Nitrate concentrations for the study area

Sites Correlated	Nitrates	Conductivity	Temperature	pH	Chloride	Alkalinity
8-7	0.76	-0.63	0.97	-0.04	8E-04	0.074
7-5	0.95	-0.17	0.96	0.436	0.639	-0.075
7-6	0.58	-0.7	0.95	7E-04	0.687	0.236
5-4	0.56	0.96	0.95	0.459	0.353	-0.052
6-4	-0.032	0.57	0.93	0.177	0.447	-0.239
5-6	0.45	0.66	1	0.359	0.272	0.593
4-3	0.78	0.92	0.97	0.577	-0.11	0.498
3-1	0.88	0.42	0.99	0.769	0.051	-0.141
3-7	0.15	0.18	0.98	0.496	-0.34	0.278

Table 1. Correlation Coefficients for select sites.

nitrate concentration, 2.13 mg/L. than the lake, 0.938 mg/L, where denitrification presumably occurred primarily due to nitrate uptake by plants in the lake.

Correlation coefficients (Table 1) support the conclusion that water seeps from Crystal Lake to the two springs below it (sites 5 and 6), further denitrification occurs, due to uptake by plants and transport through the lake sediments. A significantly larger correlation between sites 7 and 5 (correlation coefficient: 0.95) and a smaller change in the average concentration of nitrate-N of 0.39 mg/L, suggest that there may be a shorter transport time between sites 7 and 5 than between sites 7 and 6. Spring temperature fluctuations also support this interpretation. The water from the two springs below the lake flows into Wolf Creek (site 4) where nitrate concentrations increase by approximately 1 mg/L. The increase is probably due to the agricultural activities occurring in the surrounding fields.

Wolf Creek is then connected to the Decatur City Spring (site 3) via the Decatur Fault running perpendicular to the creek, supported by the correlation coefficient of 0.78 and dye trace work conducted by Monk (1997). Average nitrate-N concentrations increase from 1.5 mg/L to 2.7 mg/L, from the creek to the spring. Site 3 also displays the second highest range in nitrate-N concentrations. This is probably due to agricultural activities in the surrounding fields. North of the Decatur City Spring is another spring (site 1) with the same average nitrate-N concentrations as the Decatur City Spring.

The Decatur City Spring and Crystal Lake have a wide variation in nitrate-N concentrations over the summer. While the two sites may be connected, the differences in chemistry and low correlation coefficient may be indicative of the indirect flow path from the lake to the spring, and the increasing agricultural activity downstream. As water flows from the lake to the spring, it first travels to the two springs below it (sites 5 and 6), which then feed Wolf Creek (site 4). As the water moves from Wolf Creek to the Decatur City Spring, it picks up nitrates as base flow from the adjacent aquifer. Thus, the hydrochemistry of the lake is different from the hydrochemistry of Wolf Creek below Crystal Lake.

Conductivity.--Conductivity (Fig. 4) is the ability of a substance to conduct an electric current (Hem, 1992). Conductivity is caused by the presence of ions (charged particles) in solution and is dependent upon temperature. An increase in ion concentration causes an increase in conductivity; pure water has a very low electric conductance.

Conductivity values decrease an average of 111 µS/cm as water flows from the spring upstream (site 8) from Crystal Lake to the lake. The decrease at the lake probably occurs because it has a greater input from surface water sources which have had less water/rock interaction. From other chemical analyses, such as nitrate-N, it appears that water seeps from the lake to the two springs (sites 5 and 6) below it, where the conductivity values are elevated, consistent with water/rock interaction, as the water moves through the lake sediments and the limestone aquifer to the two springs.

Correlation statistics (Table 1) support the observation that water flows from sites 5 and 6 into Wolf Creek (site 4). Conductivity values decline at Wolf Creek although not as significantly as observed at the lake. This reduction in conductivity in Wolf Creek is another indication that water is entering the creek from another source, probably the adjacent aquifer.

From Wolf Creek to the Decatur City Spring (site 3), there is an average increase in conductivity values. of 38 µS/cm. The short rise can be attributed to increased agricultural activities, a short transport time, and water/rock interaction. The connection between these two sites is supported by the correlation coeffficient of 0.9.

The conductivity values at site 5 increase over the course of the summer. This may be due to increased iron which can be seen as a precipitate in the water emanating from the spring. The source of the iron precipitate is probably the pyrite (FeS_2) present in the Pierson Shale Member of the St. Joe Formation. The reason for the anomalous temporal increase is unknown.

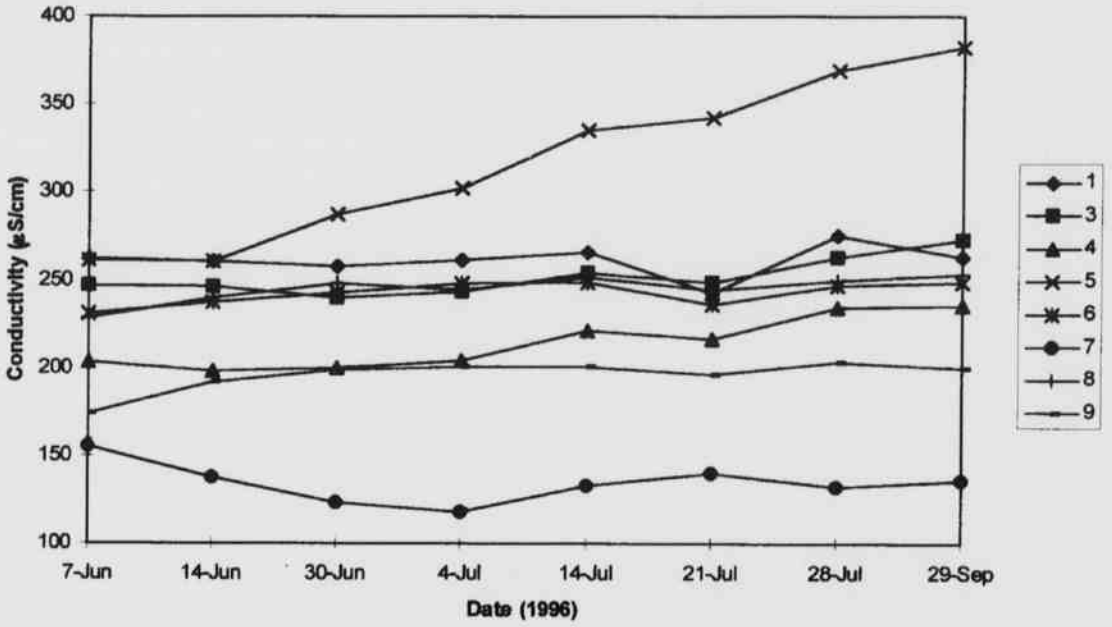

Fig. 4. Conductivity values for the study area.

Temperature.--Water temperature (Fig. 5) is lowest at the spring upstream (site 8) from Crystal Lake (average: 13.9° C) and highest in the lake. Crystal Lake (site 7) had the highest temperature range (average: 25.4° C) over the testing period due to solar heating.

From the lake to the first spring below it (site 6), the temperature range of the water decreases (average 15° C), although not to the level observed at site 8, suggesting less time for thermal equilibration and more surface water contribution. The temperature also decreased at the second

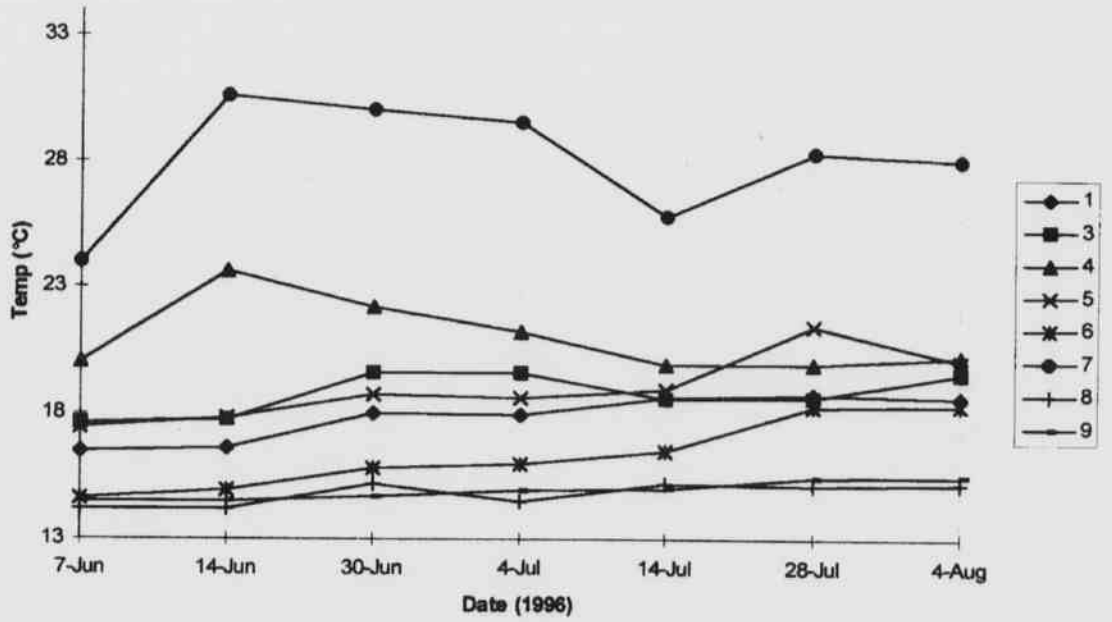

Fig. 5. Temperature values for the study area.

spring below the lake (site 5), suggesting more surface water contribution, or shorter residence time, than occurs at site 6. The high variance at site 5 may also reflect the increased surface water contribution, which if it is the lake, as hypothesized, was erratic as observed in Fig. 5. The correlation coeffficient between the lake and sites 5 and 6 are 0.96 and 0.95, respectively.

The temperature at Wolf Creek (site 4, average: 18.8° C) decreased over the testing period, due to a greater ground water contribution, probably from sites 5 and 6, and the adjacent aquifer. The correlation coefficient between Wolf Creek and Crystal Lake, the surface water components of this study is 0.8. This high correlation value is probably due to analogous solar heating at both sites.

There is a decrease in temperature from Wolf Creek to the Decatur City Spring, due to underground transport and equilibration with the aquifer, with an average temperature of 16.7° C. The range in temperature at the Decatur City Spring was the highest observed, (17.6 - 19.6° C), suggesting significant connection between surface water in Wolf Creek and the spring. The water temperature also decreased at site 1.

pH.--The pH (Fig. 6) of a solution is the measure of the hydrogen ion activity. The activity is controlled by interrelated chemical reactions that produce or consume hydrogen ions (Hem, 1992).

The pH at spring (site 8) upstream from Crystal Lake is neutral to slightly basic (average: 7.7). Downstream from site 8 at Crystal Lake (site 7), the pH increases (average: 8.5) to the most alkaline solution in the area. The increase can be attributed to decaying organic matter in the lake and to agricultural pollution. The anomalous decrease on 14-Jun may be attributed to experimental error. The correlation coeffficient between these two sites is insignificant. This may be because there is not a steady rate of decay of the organic matter.

There is an average decrease in pH of 1.25 from Crystal Lake to site 5, one of the springs below the lake. There is also a decrease in pH of 1.28 from Crystal Lake to site 6, the other spring below the lake. There is no pH correlation between either spring and the lake, or between the springs themselves.

The pH values at sites 5 and 6, which have been observed to flow into Wolf Creek is more acidic than those at Wolf Creek. This is anomalous because spring water, which reacts with carbonate bedrock should be more alkaline. Iron oxides were observed to be precipitating from both springs 5 and 6 over the course of the project. In addition, a strong hydrogen sulfide odor was noted at site 6. The water at both springs was undergoing reduction-oxidation changes. As the water passes through the lake sediments it becomes anoxic and iron, probably from pyrite weathering, goes into solution. When the water discharges from the springs it is oxygenated and the iron precipitates. The water at both springs is in disequilibrium which may account for the lower pH at these sites. Compared to Wolf Creek, there is a decrease in pH at the Decatur City Spring (site 3). The correlation coeffficient between the Decatur City Spring

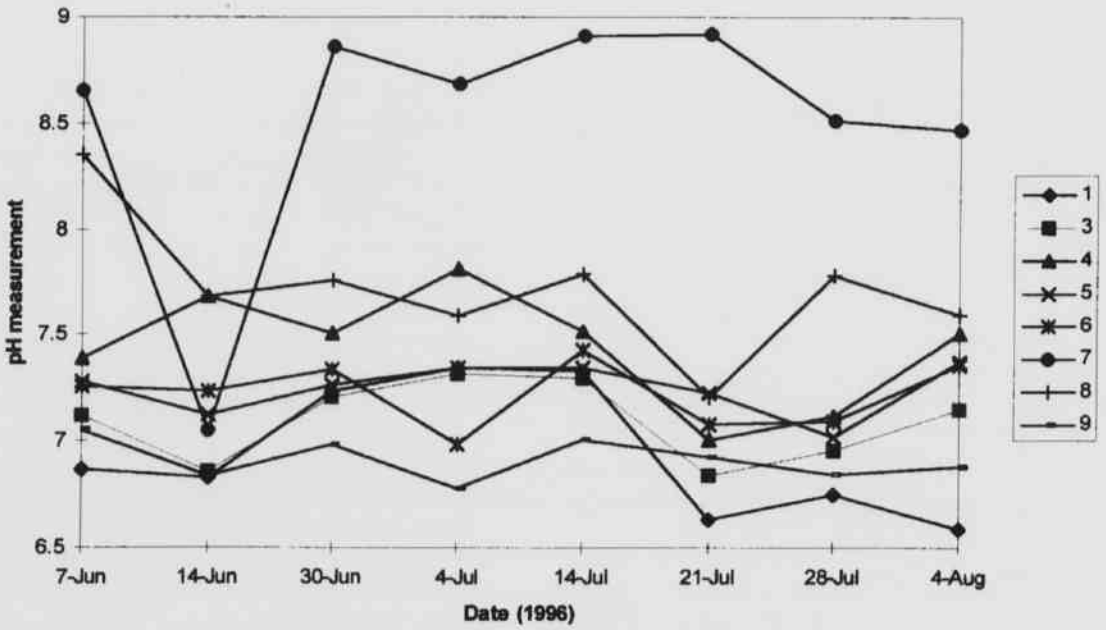

Fig. 6. pH values for the study area.

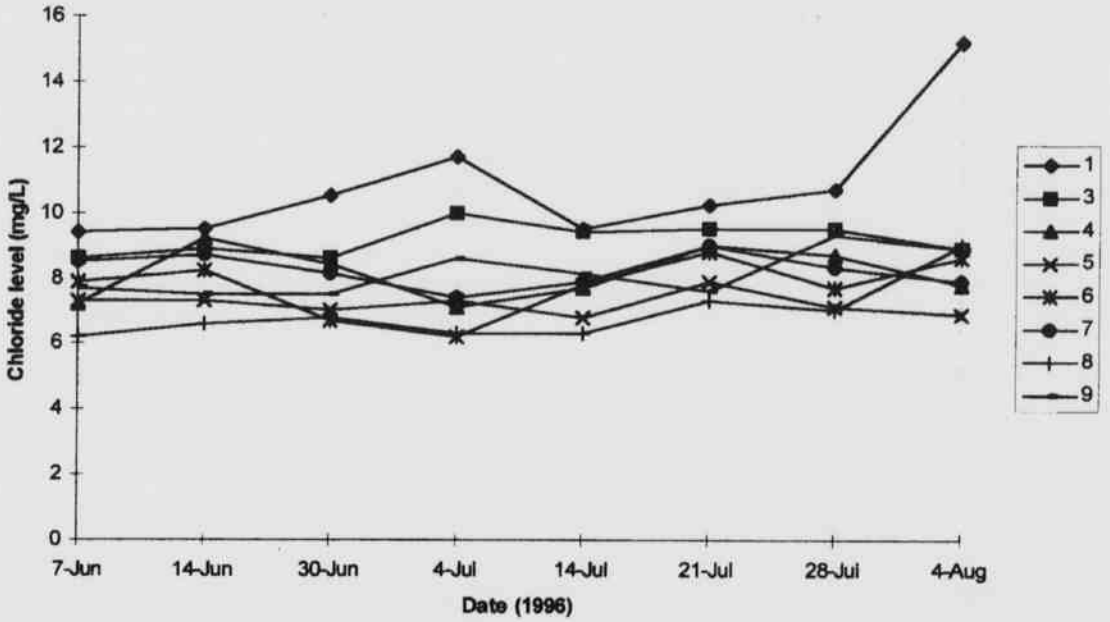

Fig. 7. Chloride values for the study area.

(site 3) and the spring north (site 1) of it is 0.8 and there is only a 0.1 variance in values, indicating these two sites are probably connected.

Chloride.--The chloride (Fig. 7) form of chlorine is the only oxidation state of significance in water exposed to the atmosphere. Chloride is present in all natural waters, but generally the concentrations are low. Chloride can be accounted for by rain, snowfall or leaching of sediments, although the third reason is less significant than the previous two (Hem ,1992). The chloride ion is also a conservative ion, which means it does not readily react with any other molecules present in the water sample.

Chloride concentrations for the spring (site 8) upstream from Crystal Lake are the lowest in the study area (average:

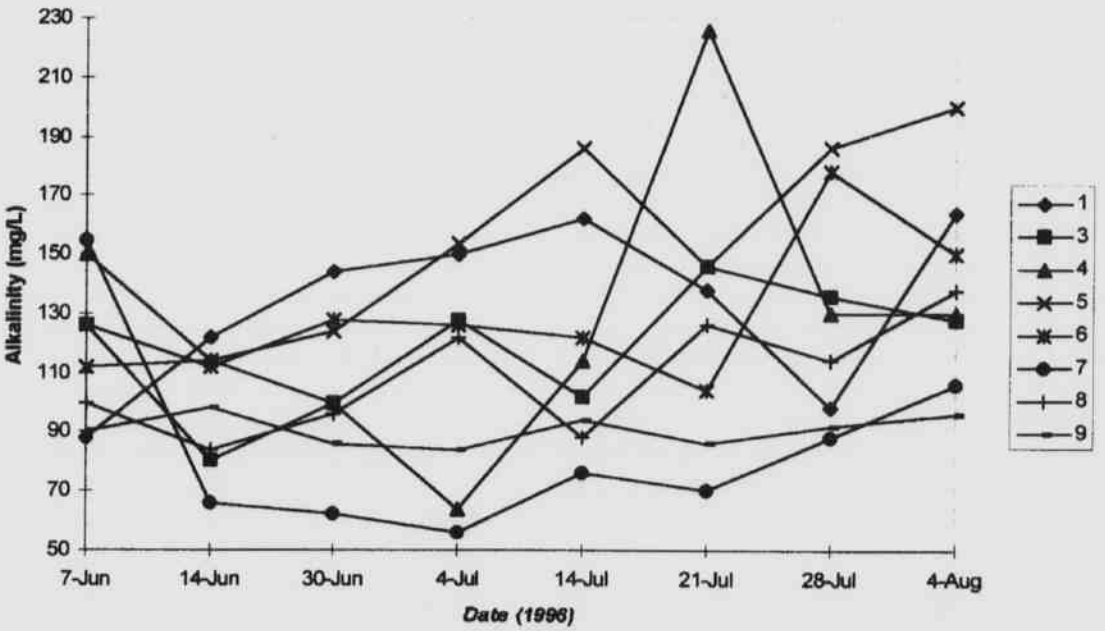

Fig. 8. Alkalinity values for the study area.

6.9 mg/L). As the water moves downstream to Crystal Lake (site 7) there is an average 1.3 mg/L rise in chloride concentrations. The chloride ions may be introduced from surrounding fields as the water is transported from site 8 to site 7. The correlation coeffficient between Crystal Lake and the two springs below it are 0.6 and 0.7 respectively, while the average change is 1 and 0.4 mg/L. The change in chloride concentrations from sites 5 and 6 to Wolf Creek is 0.9 and 0.4 mg/L, respectively.

There is an increase of chloride concentration of approximately 1 mg/L from Wolf Creek to the Decatur City Spring (site 3). The source of these chloride ions is probably the surrounding pasture land. As the water flows to the spring (site 1) north of the Decatur City Spring, the chloride concentrations remain about the same until the end of the testing period when there is a 2 mg/L differential. The increase may be indicative of an increase in agricultural activity, such as the use of animal waste as fertilizer (Adamski, 1987).

Alkalinity.--The alkalinity (Fig. 8) of a solution is defined as the capacity for solutes it contains to react with and neutralize acid. In most natural waters the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate (Hem, 1992). On examination of the alkalinity data, no definite trends could be established.

Summary and Conclusions

Based on hydrochemical and hydrogeologic data, it can be concluded that Crystal Lake, Wolf Creek, and the Decatur City Spring are hydrogeologically connected. Water flows from the lake to the two springs below it, often providing the only outflow from the lake. From the springs, the water flows into Wolf Creek, which is then connected to the Decatur City Spring via a losing segment, on the downthrown side of the Decatur Fault.

The data collected in this research also displays the impact of agriculture, specifically animals, on the ground water in the area. Five sites (sites 1,3,4,8,9) have concentrations of nitrate-N, greater than the observed background concentrations for non-agricultural areas of the Ozark Dome. Ground water flows out of the spring (site 8) upstream from Crystal Lake with an elevated nitrate-N concentration. The presence of pollutants is also indicated by the high conductivity values for this site. Water/rock interaction may be an additional source of high conductivity values. Denitrification occurs in the creek flowing out of site 8 and in the lake, resulting in lower nitrate-N concentrations at Crystal Lake.

Further denitrification occurs as the water passes through the lake and lake bottom sediments to the two springs (sites 5 and 6) below the lake. Increased conductivity values due to water/rock interaction, further substantiate that water flows from the lake to the springs. The temperature also dropped significantly in the transport system suggesting a relatively long residence time between the lake and the two springs. This may represent the time needed for the water to flow through the fine grained lake bottom sediments.

As the water flows from sites 5 and 6 into Wolf Creek (site 4), nitrate-N concentrations increase significantly, probably due to an observed increase in the agricultural activities in the surrounding pastures, where aerial photographs show more that twenty poultry houses within a one mile radius.

Wolf Creek is then connected to the Decatur City Spring via a losing segment just above the spring. Nitrate-N concentrations are further elevated. This is in correlation to an increase in agricultural activities in the vicinity of the spring. A slight increase in conductivity values can be attributed to water/rock interaction.

Agriculture is having an impact on the quality of ground water that supplies the City of Decatur. This becomes apparent with the rise of nitrate-N concentrations in ground water in the areas with surrounding pasture lands. To protect the ground water resources in this area, it was necessary to identify the areas and mechanisms by which pollutants enter the ground water flow system, and the ways the contamination spread.

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A Skeletochronological Study of Adult Spiny Softshell Turtles (*Apalone spinifera*) from Northeastern Arkansas

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Abstract

Skeletochronological techniques were used to examine age and growth in adult spiny softshell turtles (*Apalone spinifera*) from northeastern Arkansas. The diaphyseal region of femurs of 24 specimens (8 ♂♂; 16 ♀♀) was excised, decalcified in weak hydrochloric acid, and histologically prepared for light microscopy. Skeletal growth was determined from histosectioned bones by measuring femur diameters as well as by counting lines of arrested growth (LAGs) that appear between distinct periosteal layers (marks of skeletal growth = MSGs) laid down during a single growing season. Although significant positive correlations were found between carapace length (CL) and femur diameter in both males and females ($r = 0.75$; 0.92, respectively), correlation coefficients generated between CL and LAGs ($r = 0.30$; 0.45, respectively) were not significant. Sources of variation in counts of LAGs include endosteal resorption and remodeling, the lack of visible growth layers, the presence of accessory LAGs, and the compaction of MSGs; this variability introduces sampling error and diminishes the value of this technique as a method of aging adult softshell turtles.

Introduction

Skeletochronology (i.e., age determination via counting annual deposition of bone layers) provides a potential method for estimating age in vertebrates and has been widely utilized on an ever-increasing number and variety of amphibians and reptiles (e.g., see Zug et al., 1986; Castanet et al., 1988; Wake and Castanet, 1995; Castanet et al., 1996; Parham et al., 1996; Parham and Zug, 1997). The procedure involves sectioning and staining of bone tissue followed by the counting of growth layers. For these counts to be a reliable estimator of age, they must be derived from animals that undergo cyclic (seasonal) skeletal growth, such as temperate zone species (especially those living at high latitudes and/or altitudes). One assumption is that the deposition of lamellar bone tissue forms a series of periosteal growth layers (usually referred to as marks of skeletal growth--MSGs) extending outward in an annular pattern around the center of the bone. Age is, therefore, estimated by counting lines of arrested growth (LAGs) which appear as darkly-stained lines. In turtles, periosteal growth is most evident in the long bones, such as the humerus and femur, rather than in smaller bones such as the phalanges (Zug, 1991); consequently, this technique requires sacrificing of turtles.

Difficulties can arise when using skeletochronology and have been encountered in reptiles. Zug et al. (1986) and Zug (1991) emphasized the problems associated with counting LAGs in sea turtles. Annual skeletal growth layers can be altered by resorption and remodeling of bone; this is especially evident in older individuals. Peculiarities and/or inconsistent growth patterns within bones as manifested by accessory LAGs, no visible LAGs, irregular LAGs and MSGs, often make this method less dependable compared to mark/recapture studies or other aging techniques.

Male *Apalone spinifera* reach sexual maturity at a carapace length (CL) between 80-100 mm, whereas females mature at about twice the size of males (180-200 mm CL; Ernst et al., 1994). In the present study, we histologically examined femurs from adult male and female spiny softshell turtles collected in northeastern Arkansas. Our goal was to examine/test the utility of skeletochronologically aging adult softshell turtles.

Materials and Methods

The diaphyseal portion of the right femur of 24 adult *Apalone spinifera* (8 ♂♂; 16 ♀♀) from several river drainages of northeastern Arkansas (i.e., primarily from the Black, Cache, St. Francis, and White rivers) was excised using bone shears and placed into 30 ml of 1% hydrochloric acid. After seven days, bone fragments were removed from the decalcifying solution and then placed in vials of 70% ethanol. The tissue samples were prepared for routine light microscopy using paraffin histological techniques as described by Humason (1979). Tissue blocks were sectioned at a thickness of 10 µm and stained using hematoxylin (30 min); this was followed by a brief counterstaining in eosin. Femur diameters were measured from cross sections of diaphyseal bone. Museum specimens were obtained from the Arkansas State University herpetological collection; the males and females ranged from 165-199 and 132-385 mm in

CL, respectively. Regression analysis followed Sokal and Rohlf (1981); an alpha level of 0.05 was set.

Results

Femur Diameter.--Both male and female adult *Apalone spinifera* in northeastern Arkansas exhibit an increase in the femur diameter (FD) as they grow through the annual deposition of periosteal bone (Fig. 1). Regression analysis, comparing FD with CL in males, yielded the equation FD = 0.0354CL - 3.4376 and a significant positive correlation ($r = 0.75$; $P < 0.05$). Likewise, in females the equation and relationship was FD = 0.0168CL + 0.2137; $r = 0.92$ ($P < 0.05$).

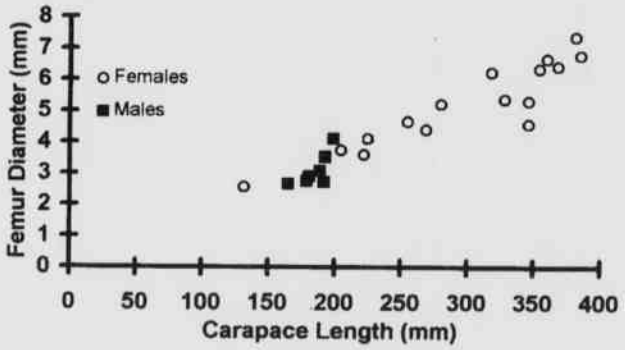

Fig. 1. Relationship between femur diameter and carapace length in adult male and female spiny softshell turtles (*Apalone spinifera*) from northeastern Arkansas.

LAGs and MSGs in Periosteal Bone.--There is no association between the number of LAGs and carapace length in either males or females (Fig. 2); the correlation coefficients for males and females ($r = 0.30$; 0.45, respectively) were not significant ($P > 0.05$). Figures 3 and 4 illustrate several transverse sections of lamellar bone for both sexes. In most cases distinctive MSGs were evident on the outer periphery of the femurs; yet, in several specimens, an absence of conspicuous LAGs (Fig. 4B and C) occurred in one region of a histosection while LAGs were observed in an adjacent region of the same section. We also noted that both males and females showed extensive remodeling via resorption within the inner core of the bone shaft (e.g., Fig. 3D; 4A and C), thus eliminating the earlier growth layers.

We observed a variety of irregularities within the periosteal layering of the MSGs in both males and females. For example, we found instances of false LAGs, called accessory LAGs, appearing within an inner MSG of a female (Fig. 4D); we also observed the separation of LAGs to form additional lines (Fig. 3E) which would produce highly constricted MSGs. Remodeling by resorption with the

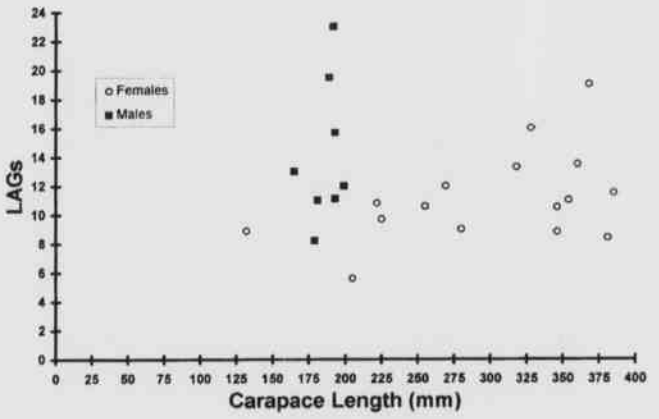

Fig. 2. Relationship between LAGs and carapace length in adult male and female spiny softshell turtles (*Apalone spinifera*) from northeastern Arkansas.

subsequent redeposition of endosteal bone formed what we termed lines of endosteal growth (LEGs; Fig. 3D). This kind of layering removes the circumferencial layering of the outermost MSGs. Erosion of innermost MSGs created a large-marrow core in the femur of some females (e.g., Fig. 4A) as compared to that of males (e.g., Fig. 3B). Females consistently exhibited greater erosion of periosteal layers than did males (compare Fig. 4B with Fig. 3A).

Estimation of Age.--Breckenridge (1955) reported on the growth rate in *A. spinifera* from Minnesota and indicated that the average adult male growth rate decreased dramatically to approximately 2 mm/year at 160 mm CL (10 years old). Adult females (10 years old), on the other hand, are about 250 mm CL, and their size at 15 years is 297 mm CL (an average annual increment of around 5.8 mm/year after 10 years of age). Because of central/core resorption, our counts of LAGs never approximated his results regarding age determination. The high variability in LAGs of males nearing 200 mm CL was clearly evident in Fig. 2. Although LAGs of females showed a slightly higher correlation than in males, they were also very inconsistent in the larger specimens.

Discussion

Our results concur with the conclusions drawn by other researchers, especially those who have examined various species of sea turtles (see Bjorndal and Zug, 1995; Parham and Zug, 1997), regarding the efficacy of skeletochronology in aging individual turtles. Zug et al. (1986) previously reviewed the potential difficulties that arise when making assumptions about annual growth layers and estimating tur-

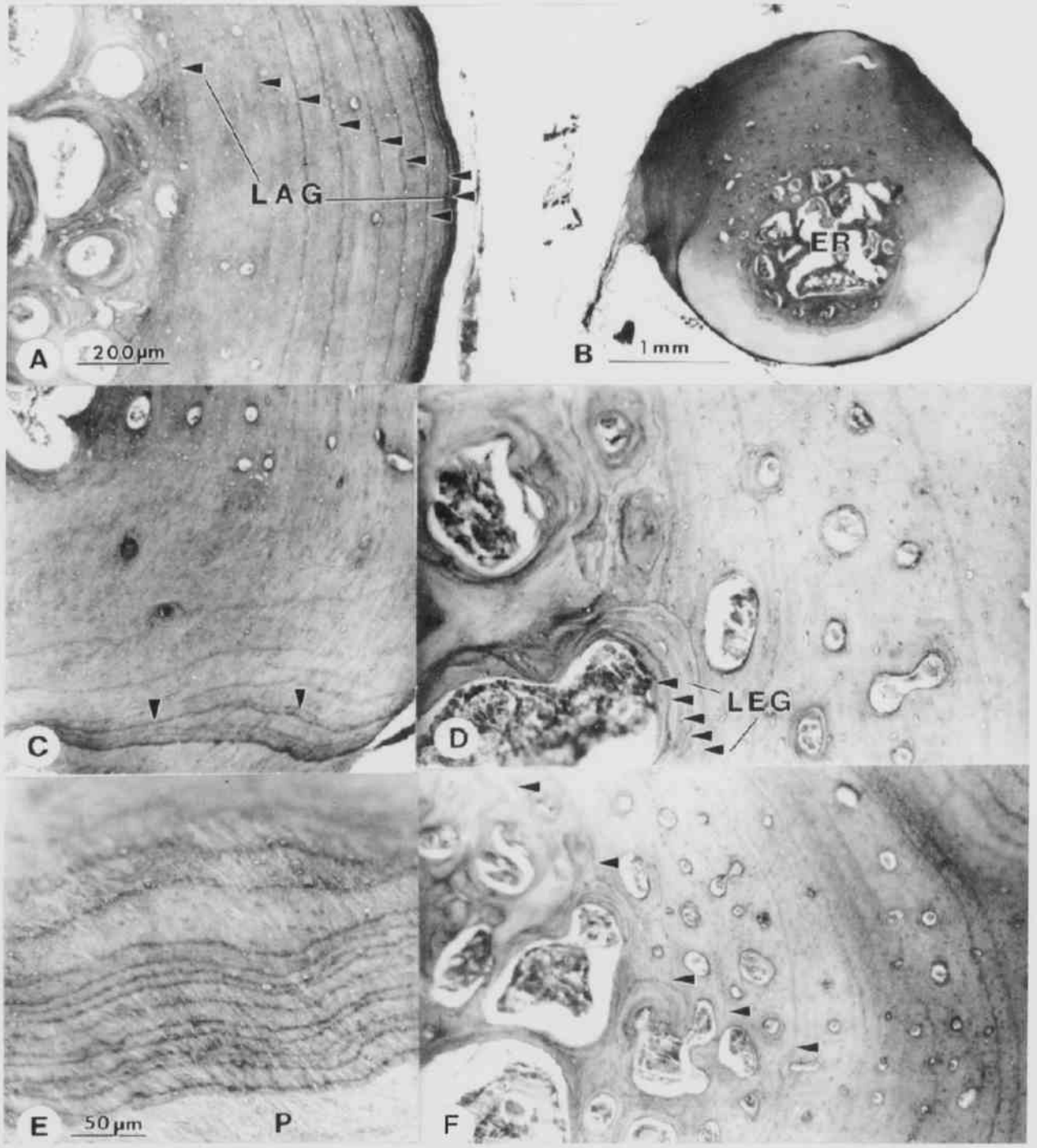

Fig. 3. Photomicrographs of transverse sections of the diaphyseal portion of femurs of adult male *Apalone spinifera* from northeastern Arkansas. A. Periosteal growth region showing LAGs in a 199 mm CL specimen (femur diameter = 4.12 mm). Extensive endosteal remodeling can be seen at the left; line in A the same for C, D and F. B. Femur (2.72 mm in diameter) of a specimen (192 mm CL) exhibiting 23 LAGs; ER = endosteal region). C. Periosteal bone (femur diameter 2.9 mm) in specimen 181 mm CL. Arrow at right denotes two LAGs that appear to merge into a single LAG (left arrow). A total of 11 LAGs was identified in this specimen. D. Five lines of endosteal growth (LEGs) of same bone shown in B. E. Same bone as in B; note the greatly reduced thickness of MSGs in the vicinity of the periosteum (P). E. Same bone as in B; extensive endosteal resorption has invaded MSGs and has begun to alter circular arrangement of LAGs.

Fig. 4. Photomicrographs of transverse sections of the diaphyseal portion of femurs of adult female *Apalone spinifera* from northeastern Arkansas. A. Section of bone (4.12 mm in diameter) from a female 225 mm CL. Compare the spacious endosteal region (ER) to that of the male in Fig. 3B. B. Bone section from 318 mm CL specimen showing periosteal region illustrating the lack of distinct LAGs; magnification the same as in C. C. Same specimen as B; periosteal region (PR) half the size as in B; ER = endosteal region. D. Section of bone (3.60 mm in diameter) from a female 222 mm CL illustrating accessory (Acc) LAGs and the next discernible LAG (upper right); at left arrows indicate separate LAGs that merge at the right; note the irregular LAGs (botton of photo). E. Same specimen as in D; note the regular and constant thickness of outermost MSGs (between arrows or LAGs).

tle age. We observed that the number of LAGs varied dramatically in both sexes of *A. spinifera*. Because remodeling and resorption can be pronounced in both medullary and periosteal bone, growth patterns observed by strictly counting the number of existing MSGs will not yield the total age of individual turtles. Others methods as discussed by Zug (1990) or Zug and Parham (1996) which use a protocol to estimate the total number of MSGs (= age in years) may provide a more accurate means of age estimation in *A. spinifera*.

We conclude that caution must be exercised when using this method of age determination. If used in conjunction with other aging techniques, skeletochronology can, at least, contribute to an overall understanding of seasonal growth and age structure in known populations of turtles.

ACKNOWLEDGMENTS.—We are grateful to Kari Kemmerer for her laboratory assistance. We also thank the Arkansas Game and Fish Commission for scientific collecting permits. George R. Zug provided us with unpublished data on skeletochronology in sea turtles and helpful suggestions that benefitted the completion of this manuscript.

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First Records for the Blackmask Racer (*Coluber constrictor latrunculus*) in Eastern Arkansas

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Abstract

The presence of the blackmask racer (*Coluber constrictor latrunculus*) in eastern Arkansas was first demonstrated by examination of a series of color slides of live specimens now preserved and deposited in the Arkansas State University Museum of Herpetology. Adult color pattern is of paramount importance in the definition of subspecies of *C. constrictor*, and this is especially true for *C. c. latrunculus*. This subspecies is characterized by a conspicuous black stripe that extends from the postnasal, through the eye and onto the temporals or anterior dorsal scales. The dorsum is slate gray, and the venter is a pale grayish blue. These identifying color characteristics tend to either fade or be obscured following preservation. *Coluber c. latrunculus* also has a larger average number of both ventrals and subcaudals when compared to other subspecies of racers in Arkansas. This subspecies was described in 1970 from populations occupying the lower Mississippi River Valley of Louisiana. Recent field guides place the subspecies throughout the alluvial plain and adjacent areas of western Mississippi. With the addition of the blackmask racer, Arkansas now has a total of four racer subspecies, each occupying different habitats within the state.

Introduction

Racers (*Coluber constrictor*) are members of the family Colubridae and are long, slender, fast-moving terrestrial snakes that can grow to lengths up to around 1.8 m (Boundy, 1995). This is a geographically-variable, polytypic species with 11 known subspecies occurring in the United States (Wilson, 1978). Color patterns are often the most effective means used to distinguish one subspecies from another (Wilson, 1970).

In December 1996, while examining a series of color slides of Arkansas racers found in the Arkansas State University herpetology collection, I noticed a postocular stripe on the sides of the heads of several specimens from eastern Arkansas (Fig. 1). Based on comparisons with the description of the blackmask racer (*C. c. latrunculus*), a subspecies known to occur in the lower Mississippi Alluvial Plain in the neighboring states of Louisiana and Mississippi (Wilson, 1970; Cliburn, 1979; Dundee and Rossman, 1989; Conant and Collins, 1991), I report herein, for the first time, the presence of *C. c. latrunculus* in Arkansas. In addition, I compare this racer with the other forms known to occur within the state.

Fig. 1. Adult specimen (ASUMZ 18609) of the blackmask racer (*Coluber constrictor latrunculus*) from Jonesboro (Craighead County), Arkansas.

Materials and Methods

A total of 202 specimens of four subspecies of *Coluber constrictor* housed in the Arkansas State University herpetological collection (ASUMZ) was examined during this investigation. Most of the specimens were collected from Arkansas and were deposited in the collection since 1984.

All snakes, except juveniles, were sexed; the snout-vent length (SVL) and tail length were measured to the nearest mm. Counts of the number of ventrals and subcaudals were also recorded from a subsample of adult snakes; mean values for the scale counts are accompanied by ± one standard deviation. The color pattern of preserved specimens in all subspecies normally fades, obscuring critical diagnostic features useful in separating races of *C. constrictor* (Wilson, 1970); however, color slides and photographs of live ASUMZ specimens were available to aid in evaluating differences among subspecies.

Results and Discussion

Color Pattern and Distribution of Arkansas Subspecies of Racers.--The southern black racer (*C. c. priapus*) is the most widespread race in the state (Conant and Collins, 1991). This subspecies possesses a mostly shiny bluish-black dorsum; the venter varies in color from a pale bluish-gray to mostly black. The belly of some southern black racers may be pale cream, buff, or white. The chin and throat of *C. c. priapus* are normally white, but this area can possess some black markings, especially in specimens from the southern and western counties. The southern black racer ranges throughout most of the Interior Highlands and Gulf Coastal Plain.

Two racers have mostly marginal distributions in the state. The buttermilk racer (*C. c. anthicus*), found in south-central Arkansas, usually possesses a mixture of white, yellow and pale blue scales on the dorsum; the venter is white, but can have a suffusion of ivory-yellow or gray down the middle of the belly (Wilson, 1970; Tumlison and Gann, 1988; Conant and Collins, 1991). The buttermilk racer is restricted to pine/hardwood areas of the western Gulf Coastal Plain. Eastern yellowbelly racers (*C. c. flaviventris*) occupy native grasslands and prairies of northwestern and extreme northcentral Arkansas. They possess a variable coloration; the dorsum can be brown, tan, gray, olive-green, or dark blue (Auffenberg, 1955). The belly is usually yellowish, but can also be a pale cream. In Arkansas, southern black racers can occur in habitats similar to those of the eastern yellowbelly racer.

The blackmask racer (*C. c. latrunculus*) is the second most widely-distributed racer in the state and is most similar to the southern black racer in appearance. The range of this racer is restricted to the Mississippi Alluvial Plain or Delta region of eastern Arkansas; however, *C. c. latrunculus* also occurs in the Missouri bootheel (Dunklin County; ASUMZ 2375). Wilson (1970) described the *C. c. latrunculus* from southcentral Louisiana. This race has a slate gray, black, or bluish-black dorsum, and the venter is usually pale cream. A conspicuous black stripe extends from the postnasal and upper surfaces of the supralabials, leads through and beneath the eye, and extends onto the temporals (Fig. 2). Dundee and Rossman (1989) illustrated this subspecies and compared its unique head coloration with that of the other races found in Louisiana. Wilson (1970) stated that the preferred habitat for this subspecies was bottomland forest of the lower Mississippi River Valley. Lohoefener and Altig (1983) discussed the distribution of the blackmask racer in Mississippi, noting its presence in extreme southwestern counties, as documented by Cliburn (1979). More recently, Conant and Collins (1991) indicated the range of this subspecies to extend throughout much of western Mississippi. The blackmask racer occurs in bottomland habitats of eastern Arkansas, but also occurs on Crowley's Ridge (a narrow, low-elevated, eroded ridge extending from southeastern Missouri to Helena, Arkansas).

Morphometric Dimensions and Scale Counts in Arkansas Subspecies of Racers.--Wilson (1970) noted significant distinctions in the number of ventrals between *C. c. latrunculus* and other racers in Louisiana. In all cases, the blackmask racer possessed the highest average number of ventrals in both males and females when compared to the other races. He also found that the number of subcaudals was a less meaningful feature to separate subspecies, because of the high percentage of incomplete tails in all racers; however, some major differences were observed among the Louisiana subspecies of racers.

In a sample of Arkansas *C. c. latrunculus*, the number of ventrals in males averaged 174.0 ± 2.9 (n = 22; range, 170-177) and in females, 176.2 ± 4.0 (n = 20; range, 169-183). The number of subcaudals in this subspecies averaged 93.9 ± 4.9 (n = 15; range, 85-103) in males, and the number in females averaged 88.5 ± 6.1 (n = 14; range, 77-96). By comparison, in *C. c. priapus*, the number of ventrals in males averaged 170.5 ± 2.7 (n = 23; range, 166-175) and in females, 172.7 ± 4.3 (n = 28; range, 169-181). The number of subcaudals is this subspecies averaged 95.4 ± 5.3 (n = 21; range, 84-107) in males, and the number in females averaged 87.9 ± 5.5 (n = 11; range, 82-102).

Only a limited number of specimens of *C. c. anthicus* and *C. c. flaviventris* were available for examination. In *C. c. anthicus*, the number of ventrals in males averaged 168.0 (n = 2; range, 166-169) and in females, 172.0 (n = 3; range, 170-175). The number of subcaudals is this subspecies averaged 96.0 (n = 2) in males, and the number in females averaged 89.5 (n = 2; range, 88-91). In *C. c. flaviventris*, the number of ventrals in males averaged 167.7 (n = 3; range, 164-172) and in females, 170.7 ± 3.5 (n = 9; range, 167-175). The number of subcaudals is this subspecies averaged 91.0 (n = 3; range, 80-97) in males, and the number in females averaged 86.8 ± 4.8 (n = 4; range, 81-92).

The average number of ventrals and subcaudals in the Louisiana sample of *C. c. latrunculus* averaged higher (male,

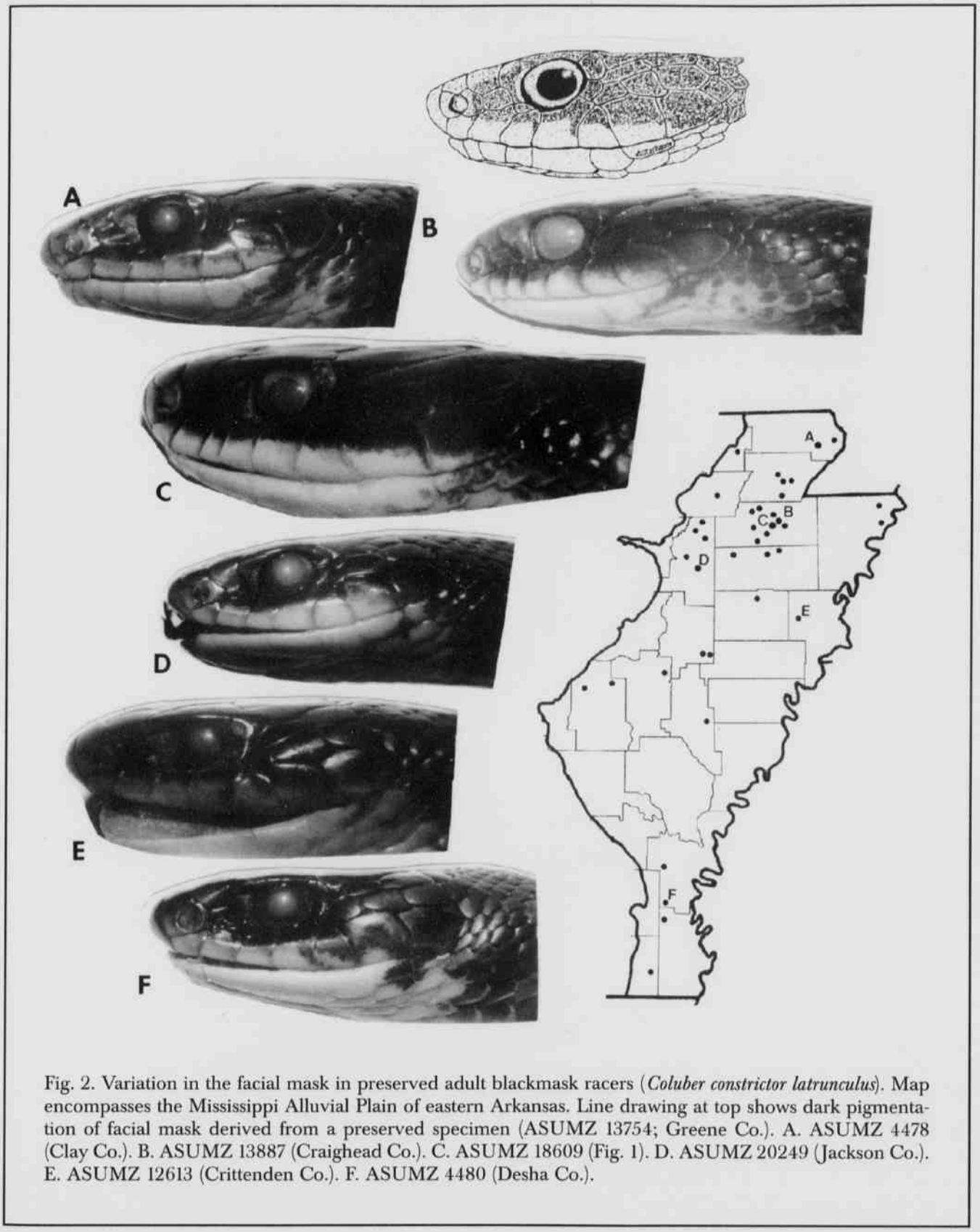

Fig. 2. Variation in the facial mask in preserved adult blackmask racers (*Coluber constrictor latrunculus*). Map encompasses the Mississippi Alluvial Plain of eastern Arkansas. Line drawing at top shows dark pigmentation of facial mask derived from a preserved specimen (ASUMZ 13754; Greene Co.). A. ASUMZ 4478 (Clay Co.). B. ASUMZ 13887 (Craighead Co.). C. ASUMZ 18609 (Fig. 1). D. ASUMZ 20249 (Jackson Co.). E. ASUMZ 12613 (Crittenden Co.). F. ASUMZ 4480 (Desha Co.).

followed by female--178.0, 180.4 and 96.1, 93.7, respectively) than the values found in my Arkansas sample in this subspecies. These differences can be attributed to clinal variation as discussed by Auffenberg (1955). As observed in Louisiana populations, scale counts for Arkansas specimens of this race were noticeably greater than for the other races in the state.

Facial Stripe in the Blackmask Racer in Arkansas.--Figure 2 illustrates the variation in the facial mask of the *C. c. latrunculus* in eastern Arkansas. Although the mask is quite vivid in live adult snakes (Fig. 1), in preservative the pigmentation of this distinct mask is most obvious only in the preocular region and cannot be clearly detected in the neck region as it blends and fades onto the temporal scales. No sexual differences were observed in mask development. The spread of dark pigmentation from the mask onto the supralabials is a variable feature in the racers examined. In many of the preserved snakes from northeastern Arkansas, the lower edge of the mask penetrated along contiguous borders of the supralabial scales, thereby producing a sawtooth edge effect (e.g., Fig. 2B). In other specimens, a straight-line lower edge to the mask was observed (Fig. 2D). In contrast, nearly all of the supralabials' surface area in *C. c. priapus* is covered by dark pigmentation.

Region of Intergradation.--No intergradation zone could be firmly established by Wilson (1970) between the three subspecies *latrunculus*, *priapus*, and *anthicus* in northern Louisiana; the same can be said for these subspecies in southern Arkansas. Given the range extension for *C. c. latrunculus* as shown in Fig. 2, the range of *C. c. priapus* within the eastern Ozark Plateau counties of Arkansas (and probably includes areas in southeastern Missouri as well) appears constricted into a narrow band or bottlenecked corridor separating *C. c. flaviventris* (to the northwest) and *C. c. latrunculus* to the southeast (see range map in Conant and Collins, 1991). This corridor will likely contain intergrades between and among these subspecies (*flaviventris*, *latrunculus*, and *priapus*), but live specimens will be necessary to clarify the details of intergradation, as indicated by color pattern.

Conclusions

The present study documents a major range extension of the blackmask racer into the Mississippi Alluvial Plain of eastern Arkansas. This subspecies also inhabits the higher elevations along Crowley's Ridge. The characteristic facial mask in this racer is distinct in live adult specimens; the mask is also retained in preserved snakes as a darkly-pigmented region extending from the preocular area onto the temporal scales. Blackmask racers average higher ventral and subcaudal counts than do other subspecies of racers in Arkansas. Further study is required to understand any intergradation among the four subspecies within the state.

ACKNOWLEDGMENTS.— I thank Larry D. Wilson for reviewing the manuscript and making many helpful suggestions which greatly improved its content. Specimens were collected under the authority of the Arkansas Game and Fish Commission (Scientific Collection Permit no. 34).

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A Floristic Survey And Annotated Checklist of The Pine Bluff Arsenal

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Abstract

We conducted a floristic survey of the Pine Bluff Arsenal during the spring, summer, and fall of 1996. In total, 622 taxa representing 113 families and 351 genera were identified and compiled into an annotated checklist. The largest families were Asteraceae (79 genera), Poaceae (73 genera). Fabaceae (41 genera), and Cyperaceae (38 genera). Exotic species composed only 8.5% of the flora. Fifty-five of the specimens represent new records for Jefferson County.

Introduction

The Arkansas Field Office of The Nature Conservancy was contracted to compile an annotated floral checklist and conduct a threatened and endangered plant species and natural areas inventory of the U. S . Army Pine Bluff Arsenal (PBA) in Jefferson County, Arkansas. PBA is located on the west bank of the Arkansas River. It is approximately 51.6 km southeast of Little Rock, AR and 4.8 km northwest of Pine Bluff, AR. Currently the arsenal covers 6050.2 ha with 4392.7 ha in forest. The remaining acres consist of lawns, buildings, roads, railroads, lakes and streams, wildlife food plots, and open fields (Becker, 1992). Most of PBA lies within the West Gulf Coastal Plain physiographic province. However, a small portion, the Arkansas River floodplain around Yellow Lake and Eastwood Bayou, lies within the Mississippi Alluvial Plain physiographic province.

The arsenal topography is generally flat with poor drainage. The northernmost portion is characterized by rolling hills and numerous streams. The area within the Mississippi Alluvial Plain physiographic region is about 13.7 meters lower in elevation than the rest of the arsenal. Drainage is generally toward the Arkansas River. Topographic elevations range between 59.6 to 103.7 meters above mean sea level (msl) sloping west to east with the normal pool of the Arkansas River, which flows just to the east of PBA, positioned at about 59.6 meters above msl. Adjacent to the Arkansas River, elevations increase abruptly at the existing bluffline to about 73.2 meters above msl. Slopes increase more gradually westward toward the maximum elevation in the northwest corner of the arsenal (Bennett et al., 1990).

The area in and around PBA has been subjected to a large amount of disturbance. Before the establishment of PBA in 1941, a large portion of the area was used for agricultural purposes (Bennett et al., 1990). When PBA was established, activities included loading incendiary bombs, manufacture of war gases, filling of bombs with chemicals, incendiary and smoke munitions, chemical agents and chemical filled munitions, and storage of these munitions (Becker, 1992).

Current activities at PBA include the manufacture of incendiary and smoke munitions and storage of these, chemical agents and toxic compounds. Timber management includes selective cutting of timber in prescribed areas. Recreational activities such as hunting and fishing also occur at PBA. Lakes and ponds are manipulated to improve fishing and wildlife plots have been established to improve hunting (Becker, 1992).

Materials and Methods

Weekly collections were made during spring, summer, and fall seasons of 1996. The entire arsenal, with the exception of the small area where chemical agents are stored, was surveyed.

Plants which could not be identified in the field were collected, pressed, dried, and stored for identification through use of taxonomic keys, particularly Smith (1994). Specimens of difficult to identify groups were sent to specialists and/or compared to herbarium collections. Philip E. Hyatt assisted with *Carex*, and Dr. Edwin Smith and George P. Johnson confirmed various specimens.

All collected specimens were sent to either the University of Arkansas herbarium in Fayetteville, Arkansas; Arkansas Tech University herbarium; or were kept at the office of The Nature Conservancy, Little Rock, Arkansas.

Plant nomenclature follows Smith (1994). The determination of a plant being exotic was made primarily by using Gleason and Cronquist (1991), but Godfrey and Wooten (1979) and Burns and Honkala (1990) were also used. County records were determined by using Smith (1988) and by sending specimens to Dr. Edwin B. Smith,

University of Arkansas, Fayetteville.

Results

We have compiled a checklist of 622 taxa representing 113 families and 351 genera. The largest families were Asteraceae (79 genera), Poaceae (73 genera), Fabaceae (41 genera), and Cyperaceae (38 genera). The largest genera were *Carex* (15 taxa), *Panicum* (15 taxa), *Quercus* (12 taxa), *Juncus* (11 taxa), Eupatorium (9 taxa), *Solidago* (8 taxa), and *Ludwigia* (8 taxa). Fifty-five of the taxa represent new records for Jefferson County. Interestingly, even though PBA has been subjected to a large amount of disturbance, only 8.5% of the flora (53 taxa) was composed of exotics.

No federally listed threatened or endangered plant species were located at PBA. However, seven species listed by the Arkansas Natural Heritage Commission as plants of special concern were found. They were *Carex atlantica* subsp. *capillacea*, *Chamaelirium luteum*, *Eleocharis flavescens*, *Eleocharis microcarpa*, *Eupatorium hyssopifoilum* var. *hyssopifoilum*, and *Scleria pauciflora*.

Annotated Checklist

The checklist is arranged alphabetically according to family, genus, species, subspecies, and/or variety. Family concepts follow Cronquist (1988) and nomenclature follows Smith (1994). Entries have the following format: taxon name, author, if the taxa represents a new county record for Jefferson County (R), and if it is an exotic (E).

Acanthaceae
Justicia ovata (Walt.) Lindau var. *lanceolata* (Chapm.) R. W. Long
Ruellia humilis Nutt. var. *humilis*

Aceraceae
Acer negundo L.
Acer rubrum L. var. *drummodi*(H & A) Sarg.
Acer rubrum L. var. *rubrum*
Acer saccharinum L.

Alismataceae
Alisma subcordatum Raf. ;(R)
Echinodorus cordifolius (L.) Griseb.
Sagittaria montevidensis Cham. & Schul. subsp. *calycina* (Engelm.) Bogin

Amaranthaceae
Alternanthera philoxeroides (Mart.) Griseb. ;(E)
Amaranthus rudis Sauer

Amaryllidaceae
Agave virginica L.
Hymenocallis liriosme (Raf.) Shinners

Anacardiaceae
Rhus copallina L.
Rhus glabra L.
Toxicodendron radicans (L.) Kuntze

Annonaceae
Asimina triloba (L.) Dunal

Apiaceae
Chaerophyllum procumbens (L.) Crantz. var. *procumbens* ;(R)
Cicuta maculata L.
Daucus pusillus Michx.
Eryngium prostratum Nutt.
Eryngium yuccifolium Michx.
Hydrocotyle ranunculoides L. f.
Ptilimnium nuttallii (DC.) Britt.
Sanicula canadensis L.
Spermolepis divaricata (Walt.) Britt.
Trepocarpus aethusae Nutt.

Apocynaceae
Apocynum cannabinum L.
Trachelospermum difforme (Walt.) Gray

Aquifoliaceae
Ilex decidua Walt.
Ilex opaca Ait.

Araceae
Arisaema dracontium (L.) Schott

Araliaceae
Aralia spinosa L.
Hedera helix L. ;(E)

Aristolochiaceae
Aristolochia serpentaria L.
Aristolochia tomentosa Sims ;(R)

Asclepiadaceae
Asclepias longifolia Michx. subsp. *hirtella* (Pennell) Farmer & Bell
Asclepias tuberosa L.
Gonolobus gonocarpos (Walt.) Perry

Asteraceae
Ambrosia artemisifolia L.
Ambrosia trifida L.
Aster lanceolatus Willd.
Aster lateriflorus (L.) Britt.

Aster paludosus Ait. subsp. *hemisphericus* (Alex.) Cronq.
Aster umbellatus Mill.
Baccharis halimifolia L.
Bidens aristosa (Michx.) Britt.
Bidens discoidea (T. & G.) Britt.
Bidens laevis (L.) BSP. ;(R)
Boltonia diffusa Ell.
Chrysopsis pilosa Nutt.
Cirsium altissiumum (L.) Spreng.
Cirsium carolinianum (Walt.) Fern.
Conyza canadensis (L.) Cron. var. *canadensis*
Coreopsis lanceolata L.
Coreopsis tinctoria Nutt. var. *tinctoria*
Coreopsis tripteris L.
Croptilon divaricatum (Nutt.) Raf.
Echinacea pallida (Nutt.) Nutt.
Eclipta prostrata (L.) L.
Elephantopus carolinianus Raeusch.
Elephantopus tomentosa L.
Erechtites hieraciifolia (L.) Raf. ex DC. var. *hieraciifolia*
Erigeron philiadelphicus L.
Erigeron strigosus Muhl. ex Willd.
Erigeron tenuis T. & G.
Eupatorium album L.
Eupatorium capillifolium (Lam.) Small
Eupatorium coelestinum L.
Eupatorium hyssopifolium L. var. *hyssopifolium*
Eupatorium perfoliatum L. var. *perfoliatum*
Eupatorium rotundifolium L.
Eupatorium semiserratum DC.
Eupatorium serotinum Michx.
Euthamia leptocephala (T. & G.) Greene
Gnaphalium purpureum L. var. *purpureum*
Helianthus angustifolius L.
Helianthus hirsutus Raf.
Helianthus mollis Lam.
Helenium amarum (Raf.) Rock
Helenium flexuosum Raf.
Heterotheca graminifolia (Michx.) Shinners
Hieracium gronovii L.
Krigia cespitosa (Raf.) K. L. Chambers
Krigia dandelion (L.) Nutt.
Krigia virginica (L.) Willd.
Lactuca canadensis L.
Lactuca floridana (L.) Gaertn. var. *floridana*
Liatris aspera Michx.
Liatris pycnostachya Michx.
Liatris squarrosa (L.) Michx. var. *hirsuta* (Rydb.) Gaiser
Mikania scandens Willd.
Pluchea camphorata (L.) DC.
Pluchea foetida (L.) DC. ;(R)
Polymnia uredalia (L.) L.
Prenanthes altissima L.
Pyrrhopappus carolinianus (Walt.) DC
Rudbeckia grandiflora (Sweet) DC. var. *alismaefolia* (T. & G.) Cronq.
Rudbeckia hirta L.
Senecio glabellus Poir.
Senecio tomentosus Michx.
Silphium integrifolium Michx.
Solidago canadensis L.
Solidago hispida Muhl. ex Willd.
Solidago nemoralis Ait.
Solidago odora Ait.
Solidago petiolaris Ait.
Solidago radula Nutt.
Solidago rugosa Mill.
Solidago ulmifolia Muhl. var. *palmeri* Cronq. ,(R)
Sonchus asper (L.) Hill ;(E)
Taraxacum officinale Wiggers ;(E)
Verbesina helianthoides Michx.
Vernonia missurica Raf.
Vernonia missurica x *texana*
Vernonia texana (Gray) Small
Xanthium strumarium L.

Azollaceae
Azolla mexicana Presl

Balsaminaceae
Impatiens capensis Meerb.

Berberidaceae
Podophyllum peltatum L.

Betulaceae
Alnus serrulata (Ait.) Willd.
Betula nigra L.
Carpinus caroliniana Walt.
Corylus americana Walt.
Ostrya virginiana (P. Mill.) K. Koch

Bignoniaceae
Bignonia capreolata L.
Campsis radicans (L.) Seem.
Catalpa speciosa Warder

Boraginaceae
Cynoglossum virginiana L.
Heliotropium indicum L. ;(E)
Myosotis verna Nutt.

Brassicaceae
Cardamine hirsuta L.
Cardamine pensylvanica Muhl. ex Willd.
Descurainia pinnata (Walt.) Britt.
Erysimum repandum L. ;(R);(E)
Lepidium virginicum L. var. medium (Greene) Hitchc. ;(R)

Lepidium virginicum L. var. *virginicum*
Rorippa palustris (L.) Besser subsp. *fernaldiana* (Butt. & Abbe) Jonsell
Sibara virginica (L.) Rollins

Callitrichaceae
Callitriche heterophylla Pursh emend. Darby var. *heterophylla* ;(R)

Campanulaceae
Lobelia appendiculata A. DC.
Lobelia cardinalis L.
Lobelia puberula Michx.
Lobelia spicata Lam.

Caprifoliaceae
Lonicera japonica Thunb. ;(E)
Lonicera sempervirens Ait.
Sambucus canadensis L.
Viburnum rufidulum Raf.

Caryophyllaceae
Cerastium glomeratum Thuill. ;(E)
Cerastium vulgatum L. ;(E)
Sagina decumbens (Ell.) T. & G.
Scleranthus annuus L. ;(E)
Stellaria media (L.) Villars ;(E)

Celastraceae
Euonymus americanus L.

Ceratophyllaceae
Ceratophyllum demersum L.

Cistaceae
Lechea mucronata Raf.
Lechea tenuifolia Michx.

Commelinaceae
Commelina communis L. var. *communis* ;(E)
Commelina diffusa Burm. F. ;(E)
Commelina virginica L.
Tradescantia hirsutiflora Bush
Tradescantia occidentalis (Britt.) Smyth

Convolvulaceae
Cuscuta pentagona Engelm.
Ipomoea pandurata (L.) Mey.

Cornaceae
Cornus drummondii Meyer
Cornus florida L.
Cornus foemina P. Mill. subsp. *foemina*

Cupressaceae
Juniperus virginiana L.

Cucurbitaceae
Melothria pendula L.

Cyperaceae
Carex atlantica Bailey subsp. *capillaceae* (Bailey) Reznicek ;(R)
Carex annectens Bickn. var. *annectens*
Carex complanata Torr. & Hook.
Carex crinita Lam. ;(R)
Carex crus-corvi Shuttlew. ex Kuntze
Carex debilis Michx. var. *pubera* Gray ;(R)
Carex flaccosperma Dewey
Carex frankii Kunth
Carex hyalinolepis Steud.
Carex intumescens Rudge
Carex joorii Bailey ;(R)
Carex louisianica Bailey
Carex lupulina Willd.
Carex tribuloides Wahlenb.
Carex typhina Michx. ;(R)
Cyperus echinatus (L.) Wood
Cyperus erythrorhizos Muhl.
Cyperus esculentus L.
Cyperus flavescens L. var. *poiformis* (Pursh) Fern.
Cyperus pseudovegetus Steud. var. *pseudovegetus*
Cyperus strigosus L.
Eleocharis flavescens (Poir.) Urban ;(R)
Eleocharis lanceolata Fern. ;(R)
Eleocharis microcarpa Torr. ;(R)
Eleocharis obtusa (Willd.) Schultes
Eleocharis quadrangulata (Michx.) R. & S. ;(R)
Fimbristylis autumnalis (L.) R. & S.
Fimbristylis miliacea Vahl. ;(R)
Rhynchospora corniculata (Lam.) Gray
Rhynchospora globularis (Chapm.) Small
Rhynchospora glomerata (L.) Vahl.
Scirpus cyperinus (L.) Kunth
Scirpus koilolepis (Steud.) Gl.
Scirpus pungens Vahl.
Scleria ciliata Michx. var. *ciliata* ;(R)
Scleria oligantha Michx. ;(R)
Scleria pauciflora Muhl. ex Willd. ;(R)
Websteria confervoides (Poir.) Hooper ;(R)

Dioscoreaceae
Dioscorea quaternata J. F. Gmel.

Droseraceae
Drosera brevifolia Pursh

Ebenaceae

Diospyros virginiana L.

Ericaceae
Lyonia ligustrina (L.) DC.
Lyonia mariana (L.) D. Don
Rhododendron viscosum (L.) Torr.
Vaccinium arboreum Marsh.
Vaccinium elliottii Chapm.
Vaccinium fuscatum Ait.
Vaccinium pallidum Ait.
Vaccinium virgatum Ait.

Euphorbiaceae
Acalypha gracilens Gray var. *gracilens*
Acalypha rhomboidea Raf.
Acalypha virginica L.
Croton capitatus Michx.
Croton glandulosus L. var. *septentrionalis* Muell. Arg.
Crotonopsis elliptica Willd.
Euphorbia corrollata L.
Euphorbia maculata L.
Euphorbia serpens H. B. K.
Euphorbia spathulata Lam.

Fabaceae
Albizia julibrissin Durazz ;(E)
Amorpha fruticosa L.
Amphicarpaea bracteata (L.) Fern. var. *bracteata*
Apios americana Medic.
Baptisia alba (L.) Vent. var. *macrophylla* (Larisey) Isely
Centrosema virginianum (L.) Benth.
Cercis canadensis L.
Chamaecrista fasciculata (Michx.) Greene
Chamaecrista nictitans (L.) Moench var. *nictitans*
Crotalaria sagittalis L.
Desmanthus illinoensis (Michx.) MacM. ex Rob. & Fern.
Desmodium ciliare (Muhl. ex Willd.) DC.
Desmodium paniculatum (L.) DC. var. *dillenii* (Darl.) Isely
Desmodium paniculatum (L.) DC. var. *paniculatum*
Desmodium pauciflorum (Nutt.) DC. ;(R)
Desmodium viridiflorum (L.) DC. ;(R)
Galactia mohlenbrockii Maxwell
Gleditsia triacanthos L.
Gymnocladus dioica (L.) Koch
Lespedeza capitata Michx.
Lespedeza cuneata (Dumont) G. Don. ;(E)
Lespedeza hirta (L.) Hornem. var. *hirta*
Lespedeza intermedia (L.) Britt. ;(R)
Lespedeza repens (L.) Bart.
Lespedeza striata (Thunb.) H. & A. ;(E)
Lespedeza virginica (L.) Britt.
Medicago lupulina L. ;(E)
Potentilla simplex Michx.
Psoralea psoralioides (Walt.) Cory var. *eglandulosa* (Ell.) Freeman
Rhynchosia latifolia Nutt. ex T. & G.
Robinia pseudo-acacia L.
Senna marilandica (L.) Link
Sesbania macrocarpa Muhl.
Strophostyles helvula (L.) Ell.
Strophostyles leiosperma (T. & G.) Piper
Tephrosia onobrychoides Nutt.
Tephrosia virginiana (L.) Pers.
Trifolium repens L. ;(E)
Trifolium resupinatum L. ;(E)
Wisteria frutescens (L.) Poir.
Vicia sativa L. ;(E)

Fagaceae
Castanea pumila (L.) Mill. var. *pumila*
Fagus grandifolia Ehrh.
Quercus alba L.
Quercus falcata Michx. var. *falcata*
Quercus falcata Michx. var. *pagodifolia* Ell.
Quercus lyrata Walt.
Quercus marilandica Muench.
Quercus michxauxii Nutt.
Quercus nigra L.
Quercus phellos L.
Quercus shumardii Buckl.
Quercus stellata Wang. var. *paludosa* Sarg.
Quercus stellata Wang. var. *stellata*
Quercus velutina Lam.

Geraniaceae
Geranium carolinianum L.
Geranium dissectum L. ;(E)

Hamamelidaceae
Hamamelis virginiana L.
Liquidambar styraciflua L.

Hippocastanaceae
Aesculus pavia L.

Hydrocharitaceae
Limnobium spongia (Bosc.) Steud.

Hydrophyllaceae
Hydrolea uniflora Raf.

Hypericacea
Hypericum densiflorum Pursh var. *lobocarpum* (Gatt.) Svenson
Hypericum drummondii (Grev. & Hook.) T. & G.
Hypericum gentianoides (L.) B. S. P. ;(R)
Hypericum hypericoides (L.) Crantz.
Hypericum mutilum L.
Hypericum stans (Michx.) Adams & Robson

Triadenum walteri (Gmel.) Gl.

Iridaceae
Iris cristata Ait.
Sisyrinchium angustifolium P. Mill.
Sisyrinchium langloisii Greene
Sisyrinchium rosulatum Bickn.

Juglandaceae
Carya cordiformis (Wang.) K. Koch
Carya illinoensis (Wang.) K. Koch
Carya laciniosa (Michx. f.) Loud. ;(R)
Carya texana Buckl.
Carya tomentosa (Poir.) Nutt.
Juglans nigra L.

Juncaceae
Juncus acuminatus Michx.
Juncus brachycarpus Engelm.
Juncus coriaceus Mack. ;(R)
Juncus diffusissimus Buckl.
Juncus effusus L.
Juncus marginatus Rostk.
Juncus nodatus Coville
Juncus repens Michx. ;(R)
Juncus scirpoides Lam.
Juncus tenuis Willd.
Juncus validus Coville
Luzula echinata (Small) Herm. ;(R)

Lamiaceae
Cunila origanoides (L.) Britt.
Hedeoma hispidum Pursh
Lamium amplexicaule L.
Lamium purpureum L.
Lycopus virginicus L.
Monarda fistulosa L.
Monarda punctata L.
Perilla frutescens (L.) Britt ;(E)
Prunella vulgaris L.
Pycnanthemum albescens T. & G.
Pycnanthemum muticum (Michx.) Pers.
Pycnanthemum pilosum Nutt. ;(R)
Pycnanthemum tenuifolium Schrad.
Salvia lyrata L.
Scutellaria integrifolia L.
Stachys tenuifolia Willd. var. *tenuifolia*
Teucrium canadense L.

Lauraceae
Lindera benzoin (L.) Blume
Sassafras albidum (Nutt.) Nees

Lemnaceae
Lemna obscura (Austin) Daubs
Spirodela polyrhiza (L.) Schleid.
Spirodela punctata (G. F. W. Meyer) Thompson ;(E)
Wolffia brasilliensis Weddell

Lentibulariaceae
Utricularia gibba L.
Utricularia radiata Small ;(R)

Lilliaceae
Aletris farinosa L.
Allium canadense L.
Allium vineale L. ;(E)
Chamaelirium luteum (L.) Gray
Hemerocallis fulva L. ;(E)
Maianthemum paniculatum (Mart. & Gal.) Lafr.
Polygonatum biflorum (Walt.) Ell. ;(R)
Smilax bona-nox L.
Smilax glauca Walt.
Smilax rotundifolia L.
Smilax smallii Morong
Trillium recurvatum Beck
Uvularia sessilifolia L.

Linaceae
Linum medium (Planch.) Britt. var. *texanum* (Planch.) Fern.

Loganiaceae
Gelsemium sempervirens (L.) Jaume St.-Hil.

Loranthaceae
Phoradendron serotinum (Raf.) Johnston

Lycopiacae
Lycopodium appressum (Chapm.) Lloyd & Underw. ;(R)

Lythraceae
Ammannia x coccinea Rottb.
Lythrum alatum Pursh. var. *lanceolatum* (Ell.) T. & G. ex Rothrock
Rotala ramosior (L.) Koehne

Magnoliaceae
Magnolia grandiflora L. ;(E)

Malvaceae
Hibiscus laevis Allioni
Hibiscus lasiocarpos Cav.
Sida spinosa L.

Melastomataceae
Rhexia mariana L. var. *mariana*
Rhexia virginica L.

Meliaceae
Melia azedarach L. ;(E)

Menispermaceae
Cocculus carolinus (L.) DC.

Moraceae
Morus rubra L.

Myricaceae
Myrica cerifera L.

Najadaceae
Najas guadalupensis (Spreng.) Magnus ;(R)
Potamogeton diversifolius Raf.
Potamogeton pusillus L. ;(R)

Nymphaeaceae
Brasenia schreberi J. F. Gmel.
Nelumbo lutea (Willd.) Pers.

Nyssaceae
Nyssa sylvatica Marsh. var. *sylvatica*

Oleaceae
Chionanthus virginicus L.
Forestiera acuminata (Michx.) Poir.
Fraxinus americana L.
Fraxinus pennsylvanica Marsh.
Ligustrum sinense Lour. ;(E)

Onagraceae
Ludwigia alternifolia L.
Ludwigia decurrens Walt.
Ludwigia glandulosa Walt.
Ludwigia hirtella Raf.
Ludwigia leptocarpa (Nutt.) Hara
Ludwigia linearis Walt.
Ludwigia palustris (L.) Ell. ;(R)
Ludwigia peploides (H. B. K.) Raven subsp. *glabrescens* (Kuntze) Raven
Oenothera lanciniata Hill. var. *lanciniata*
Oenothera linifolia Nutt.
Oenothera speciosa Nutt.
Oenothera villosa Thunb.

Ophioglossaceae
Botrychium dissectum Spreng. var. *obliquum* Muhl.
Botrychium virginianum (L.) Sw.
Ophioglossum vulgatum L. var. *pycnostichum* Fern.

Orchidaceae
Isotria verticillata (Muhl. ex Willd.) Raf.
Listera australis Lindley
Plantanthera ciliaris (L.) Lindley
Spiranthes lacera (Raf.) Raf. var. *gracilis* (Bigelow) Luer ;(R)
Spiranthes vernalis Engelm. & Gray
Tipularia discolor (Pursh) Nutt.

Osmundaceae
Osmunda cinnamomea L.
Osmunda regalis L. var. *spectabilis* (Willd.) Gray

Oxalidaceae
Oxalis dillenii Jacq.
Oxalis violacea L.

Passifloraceae
Passiflora incarnata L.
Passiflora lutea L.

Phrymaceae
Phryma leptostachya L.

Phytolaccaceae
Phytolacca americana L.

Pinaceae
Pinus echinata Mill.
Pinus taeda L.

Plantaginaceae
Plantago lanceolata L. ;(E)
Plantago virginica L.

Platanaceae
Platanus occidentalis L.

Poaceae
Agrostis elliotiana Schultes ;(R)
Agrostis hiemalis (Walt.) B. S. P.
Agrostis perennans (Walt.) Tuckerm.
Aira elegans Willd. ex Gaudin ;(E)
Andropogon gerardii Vitman
Andropogon glomeratus (Walt.) B. S. P.
Andropogon scoparius Michx.
Andropogon virginicus L. var. *virginicus*
Aristida longisoica Poir.
Aristida oligantha Michx.
Aristida purpurascens Poir.
Arundinaria gigantea (Walt.) Muhl.
Brachyelytrum erectum (Schreb.) Beauv. ;(R)
Bromus secalinus L. ;(E)
Cenchrus incertus M. A. Curtis
Chasmanthium latifolium (Michx.) Yates
Chasmanthium laxum (L.) Yates
Chasmanthium sessiliflorum (Poir.) Yates
Cynodon dactylon (L.) Pers. ;(E)

Digitaria ciliaris (Retz.) Koel.
Digitaria ischaemum (Schreb. ex Schweigg.) Schreb. ex Muhl. ;(E)
Echinochloa crusgalli (L.) Beauv. ;(E)
Echinochloa muricata (Beauv.) Fern.
Elymus virginicus L.
Eragrostis hirsuta (Michx.) Nees
Eragrostis pectinacea (Michx.) Nees
Eragrostis pilosa (L.) Beauv.
Eragrostis spectabilis (Pursh) Steud.
Erianthus contortus Ell.
Erianthus strictus Baldw. ;(R)
Festuca arundinacea Schreb. ;(E)
Glyceria septentrionalis Hitch. var. *arkansana* (Fern.) Steyerm. & Kucera
Gymnopogon brevifolius Trin.
Hordeum pusillum
Leersia lenticularis Michx.
Leersia oryzoides (L.) Swartz
Leersia virginica Willd.
Lolium perenne L. (E)
Manisuris cylindrica (Michx.) Kuntze ;(R)
Panicum acuminatum Swartz
Panicum anceps Michx.
Panicum angustifolium Ell.
Panicum boscii Poir.
Panicum brachyanthum Steud. ;(R)
Panicum clandestinum L.
Panicum commutatum Schult.
Panicum dichotomiflorum Michx.
Panicum dichotomum L.
Panicum hians Ell.
Panicum laxiflorum Lam.
Panicum polyanthes Schult.
Panicum rigidulum Bosc. ex Nees
Panicum scoparium Lam.
Panicum verrucosum Muhl. ;(R)
Paspalum dilatatum Poir. ;(E)
Paspalum floridanum Michx.
Paspalum laeve Michx.
Paspalum setaceum Michx.
Phalaris caroliniana Walt.
Poa annua L. ;(E)
Setaria faberi Herrm ;(E)
Setaria geniculata (Lam.) Beauv.
Setaria glauca (L.) Beauv.
Sorghastrum nutans (L.) Nash
Sorghum halepense (L.) Pers. ;(E)
Tridens flavus (L.) Hitchc. var. *flavus*
Tridens strictus (Nutt.) Nash
Tripsacum dactyloides (L.) L.
Vulpia bromoides (L.) S. F. Gray ;(E)
Vulpia octoflora (Walt.) Rydb.
Zizaniopsis miliacea (Michx.) Doell & Asch.

Polemoniaceae
Phlox divaricata L. subsp. *laphamii* (Wood) Wherry ;(R)
Phlox glaberrima L.
Phlox pilosa L. subsp. *pilosa*

Polygalaceae
Polygala incarnata L.
Polygala mariana Mill. ;(R)
Polygala sanguinea L.
Polygala verticillata L.

Polygonaceae
Brunnichia ovata (Walt.) Shinners
Polygonum aviculare L.
Polygonum bicorne Raf.
Polygonum hydropiperoides Michx.
Polygonum punctatum Ell.
Polygonum ramosissimum Michx.
Polygonum virginianum L.
Rumex crispus L. ;(E)
Rumex hastatulus Baldw. ex Ell.

Polypodiaceae
Asplenium platyneuron (L.) Oakes ex D. C. Eat.
Athyrium filix-femina (L.) Roth var. *asplenioides* (Michx.) Farw.
Lorinseria areolata (L.) Presl.
Onociea sensibilis L.
Phegopteris hexagonoptera (Michx.) Fee
Polypodium polypodioides (L.) Watt var. *michauxianum* Weatherby
Polystichum acrostichoides (Michx.) Schott
Pteridium aquilinum (L.) Kuhn in Decken
Woodsia obtusa (Spreng.) Torr.

Pontederiaceae
Heteranthera limosa (Sw.) Willd. ;(R)

Portulacaceae
Claytonia virginica L.
Portulaca oleracea L. ;(E)

Primulaceae
Lysimachia lanceolata Walt. var. *lanceolata*
Lysimachia radicans Hook.

Ranunculaceae
Anemone virginiana L.
Clematis crispa L.
Clematis virginiana L.
Myosurus minimus L.
Ranunculus hispidus Michx. var. *hispidus*
Ranunculus parviflorus L. ;(E)
Ranunculus pusillus Poir.
Ranunculus sardous Crantz. ;(E)

Ranunculus sceleratus L. var. *sceleratus*
Thalictrum thalictroides (L.) Eames & Boivin

Rhamnaceae
Berchemia scandens (Hill) K. Koch
Ceanothus americanus L.
Rhamnus caroliniana Walt.

Rosaceae
Agrimonia rostellata Wallr.
Amelanchier arborea (Michx. f.) Fern.
Crataegus intricata Lange ;(R)
Crataegus marshallii Egglest.
Crataegus spathulata Michx. ;(R)
Geum canadense Jacq.
Porteranthus stipulatus (Muhl. ex Willd.) Britt.
Prunus angustifolia Marsh.
Prunus mexicana S. Wats.
Prunus serotina Ehrh.
Prunus umbellata Ell.
Rosa carolina L.
Rubus argutus Link
Rubus flagellaris Willd.
Rubus trivialis Michx.

Rubiaceae
Cephalanthus occidentalis L.
Diodia teres Walt.
Diodia virginiana L.
Galium aparine L.
Galium circaezans Michx.
Galium obtusum Bigel. subsp. *obtusum*
Galium tinctorium L.
Hedyotis australis Lewis & Moore
Hedyotis caerulea (L.) Hook.
Hedyotis crassifolia Raf.
Hedyotis purpurea (L.) T. & G.
Mitchella repens L.
Sherardia arvensis L. ;(E)

Salicaceae
Populus deltoides Marsh. subsp. *deltoides*
Salix humilis Marsh.
Salix nigra Marsh.

Sapindaceae
Cardiospermum halicababum L. ;(E)

Saururaceae
Saururus cernuus L.

Saxifragaceae
Itea virginica L.
Hydrangea arborescens L.
Penthorum sedoides L.

Scrophulariaceae
Agalinis aspera (Dougl.) Britt.
Agalinis fasciculata (Ell.) Raf.
Agalinis viridis (Small) Pennell
Aureolaria flava (L.) Farwell
Aureolaria grandiflora (Benth.) Pennell ;(R)
Gratiola neglecta Torr.
Linaria canadensis (L.) Dumont
Lindernia dubia (L.) Pennell
Mimulus alatus Ait.
Pedicularis canadensis L.
Verbascum blattaria L. ;(E)
Verbascum thapsus L. ;(E)
Veronica arvensis L. ;(E)
Veronica peregrina L.

Solanaceae
Physalis mollis Nutt. var. *mollis*
Physalis longifolia Nutt.
Solanum carolinense L.

Steracaceae
Styrax americana Lam.
Styrax grandifolia Ait. ;(R)

Symplocaceae
Symplocos tinctoria (L.) L'Her.

Taxodiaceae
Taxodium distichum (L.) Rich.

Tiliaceae
Tilia americana L.

Typhaceae
Typha domingensis Pers.
Typha latifolia L.

Ulmaceae
Celtis laevigata Willd.
Planera aquatica (Walt.) Gmelin
Ulmus alata Michx.
Ulmus americana L.
Ulmus rubra Muhl.

Urticaceae
Boehmeria cylindrica (L.) Sw.
Pilea pumila (L.) A. Gray ;(R)
Urtica chamaedryoides Pursh

Valerianaceae
Valerianella radiata (L.) Dufr.

Verbenaceae
Callicarpa americana L.
Phyla lanceolata (Michx.) Greene
Verbena brasiliensis Vell. ;(E)
Verbena officinalis L. subsp. *halei* (Small) Barber
Verbena urticifolia L.

Violaceae
Viola rafinesquii Greene
Viola sagittata Ait.
Viola sororia Willd. var. *missouriensis* (Greene) McKinney ;(R)
Viola sororia Willd. var. *sororia*

Vitaceae
Ampelopsis arborea (L.) Koehne
Ampelopsis cordata Michx.
Parthenocissus quinquefolia (L.) Planchon
Vitis aestivalis Michx.
Vitis cinerea (Engelm. in Gray) Engelm. ex Millard var. *cinerea*
Vitis riparia Michx. ;(R)
Vitis rotundifolia Michx. var. *rotundifolia*
Vitis vulpina L.

Xyridaceae
Xyris torta Sm.

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Integrating GIS and Remote Sensing with Ecosystem Research

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Abstract

In the Phase II Ecosystem Management Research Program in the Ouachita and Ozark National Forests, an interdisciplinary group of scientists are evaluating the effects and trade-offs of partial cutting methods in a replicated stand level study. Information from approximately 2,000 plots is being collected by more than fifty researchers during this five-year project with plans to continue data collection long term. To evaluate the effects of different management strategies and their interactions with forest resources, data must be brought into a common format and made available to all researchers. To this end, a data support system was developed which utilizes Geographic Information System (GIS), Global Positioning Systems (GPS) and remote sensing technologies. Aerial photography, along with digitized layers of stand and greenbelt boundaries, roads and streams, and GPSed silvicultural plot locations form a framework to which data from diverse research areas can be linked. Researchers can not only share information resources, but can graphically visualize and query both spatial and attribute data to reflect forest ecosystem changes under various management strategies. The methodology used to develop and configure this large, relational database into an easily accessible form usable in an interactive GIS program could be transferable to other areas of natural resource management.

Introduction

Ecosystem Management Research Project.--Changing attitudes toward national forests have increased demands to manage forests in a socially acceptable and ecologically sustainable manner. In response, research was initiated in the Ouachita and Ozark National Forests to investigate alternatives to clearcutting in pine and pine-hardwood stands (Mersmann et al., 1994). This research is based on the need and desire to manage national forest lands using silvicultural practices consistent with sustainable ecosystem management. The Ecosystem Management Research Program in the Ouachita and Ozark National Forests is composed of three phases. The first phase established demonstration stands that provided early evidence of the operational feasibility of selecting for various densities, compositions, and structures of pine/hardwood overstories. The second phase takes a statistical approach to study alternative silviculture treatments at the stand level and is the focus of the data support system described in this paper. The third phase is a large-scale landscape-level study designed to test the operational implementation of ecosystem management at the watershed level (Baker, 1994a).

Phase II, a replicated stand-level study, was installed in mature, shortleaf pine (*Pinus echinata* Mill.)-hardwood stands in the Ouachita and Ozark National Forests during the summer of 1993. A series of permanent and temporary sample plots was established to test and evaluate a range of partial cutting methods (seed-tree, shelterwood, single-tree and group selection) and vegetation management treatments (site preparation and release). The objectives of the study are to evaluate (1) the biologic and economic feasibility of using partial cutting methods and long-term retention of pine-hardwood overstories to establish and maintain mixed pine-hardwood stands that reflect indigenous vegetation and historical stand structure on south-facing slopes of the Ouachita Mountains and (2) the effects and trade-offs of the partial cutting methods on various commodity and non-commodity resources and values (Baker, 1994a). Thirteen treatments include both even-aged and uneven-aged reproduction cutting methods with longterm retention of various densities, compositions, and structures of overstory pines and hardwoods. Two controls, an unmanaged control and a clearcut control, are also included as part of the 13 treatments. Four levels of vegetation management are also being investigated. The effects of harvesting vegetation management treatments will be evaluated in terms of multiple resources and noncommodity values, including: plant and animal communities, arthropod and microbial communities, soils, water, cultural resources, scenic quality, recre-

ational opportunities, and harvesting and management costs. Information from approximately 2,000 plots is being collected by more than fifty researchers during this five-year project with plans to continue data collection long term.

Data Support System.--A tremendous amount of data has been collected by Phase II researchers up to this point. At a 1993 symposium, researchers reported on pretreatment conditions and preliminary findings of the Ecosystem Management Research in the Ouachita Mountains (Baker, 1994b). Papers were narrowly focused on topics such as: herbaceous plant diversity, small mammal communities, breeding birds, arthropod biodiversity, water chemistry, scenic quality, and harvest management costs. Each research team has begun to accumulate a significant amount of information on the various components of the project. Because ecosystem management is a holistic, integrated approach to managing resources, decisions are based on complex interactions of biotic and abiotic factors across the landscape (Lachowski et al., 1994). In order for Phase II researchers to evaluate treatment effects on the ecosystem as a whole and understand their spatial relationships, they must have access to information collected by other teams for each specific location and treatment. All variables must be weighed and referenced to one another before a broader focus on the ecosystem can be achieved. This GIS database support system provides an easily accessible interface through which researchers can make ecosystem level evaluations.

Materials and Methods

Database Design.--The first step in developing a data support system for the Ouachita/Ozark National Forest Ecosystem Management Research effort was to determine common denominators which applied to the data of every research team. Research topics include silviculture, biodiversity, wildlife, water quality, soils, cultural resources, visual quality, recreation, arthropod and microbial communities, as well as logging and management economics. It was also necessary to determine what types of data were being collected and devise methods to store, view, integrate and evaluate many different data formats. Data formats included tabular records, tables, charts, analyses, color slides, color and black and white photographs, stand maps, and plot diagrams. Although each research team devised data collecting methods appropriate to its needs, all data could be tied to specific real world locations where treatments had been installed at stand, plot and subplot levels.

A conceptual design was developed to integrate both spatial and tabular data from 52 stands and more than two thousand plots. Because all data can be tied to specific treatment locations, Geographic Information System (GIS) software provides a logical means to integrate research efforts. Global Positioning Systems (GPS) data serve as a coordinate framework to bring the real world data into a computer world analysis. This spatial model has evolved into a data support system which allows integration of all phases of the research.

Developing a Spatial Reference System.--Determining a coordinate reference for each treatment location was the first step in the development of this data support system. Stands were located on USGS quadrangle maps based on hand-drawn stand maps provided by Ouachita/Ozark National Forest Service personnel. The roads and streams on the quad maps were digitized in the area of each stand using PC ARC/INFO* GIS. Digitizing is the process of manually capturing spatial data and recording x, y coordinates into map features. Quad maps were then scanned into tiff images. Maps were rectified and registered using the road and stream cover in Workstation ARC/INFO* GIS. Image rectification corrects distorted image data to create a more faithful representation. Image registration serves to transform the rows and columns of a scanned image into real world x, y coordinates. These processes use georeferencing information from the digitized cover to correctly register the scanned image in geographic space (Lillesand and Kiefer, 1994). The registered quad maps were then brought into ArcView* GIS, and UTM coordinates were determined for the center of each stand. Stand locations in northwestern Arkansas and eastern Oklahoma are shown in Fig. 1.

Using coordinates for the center of each stand to guide the pilot, fall color stereo aerial photography was obtained at a scale of 1:7,200. The center aerial photo for each stand was scanned into a tiff image, registered, and used as a base map for other stand data. Registration was accomplished by first converting the tiff images to ER Mapper* files using Image Alchemy*. Then Image Alchemy and customized programs were used to convert the registered raster quad map files to ER Mapper registered images. The quad maps were used to register and rectify the aerial photos as raster images using ER Mapper. This complex procedure was necessitated by the paucity of roads and streams in the area of many stands, making it impossible to register the aerial photographs using the vector road and stream coverages. In addition, GPS coordinates were collected and differentially corrected to assist with the rectification of photos and to pinpoint various wildlife and silviculture subplots. Differential correction is a process which corrects GPS error, some of which is intentional degradation of the satellite performance by the U.S. Department of Defense. It greatly increases accuracy and is accomplished by developing a correction factor for data from a receiver placed on a known control point and then using this factor to correct rover receiver data collected during the same time frame (Oderwald and Boucher, 1997).

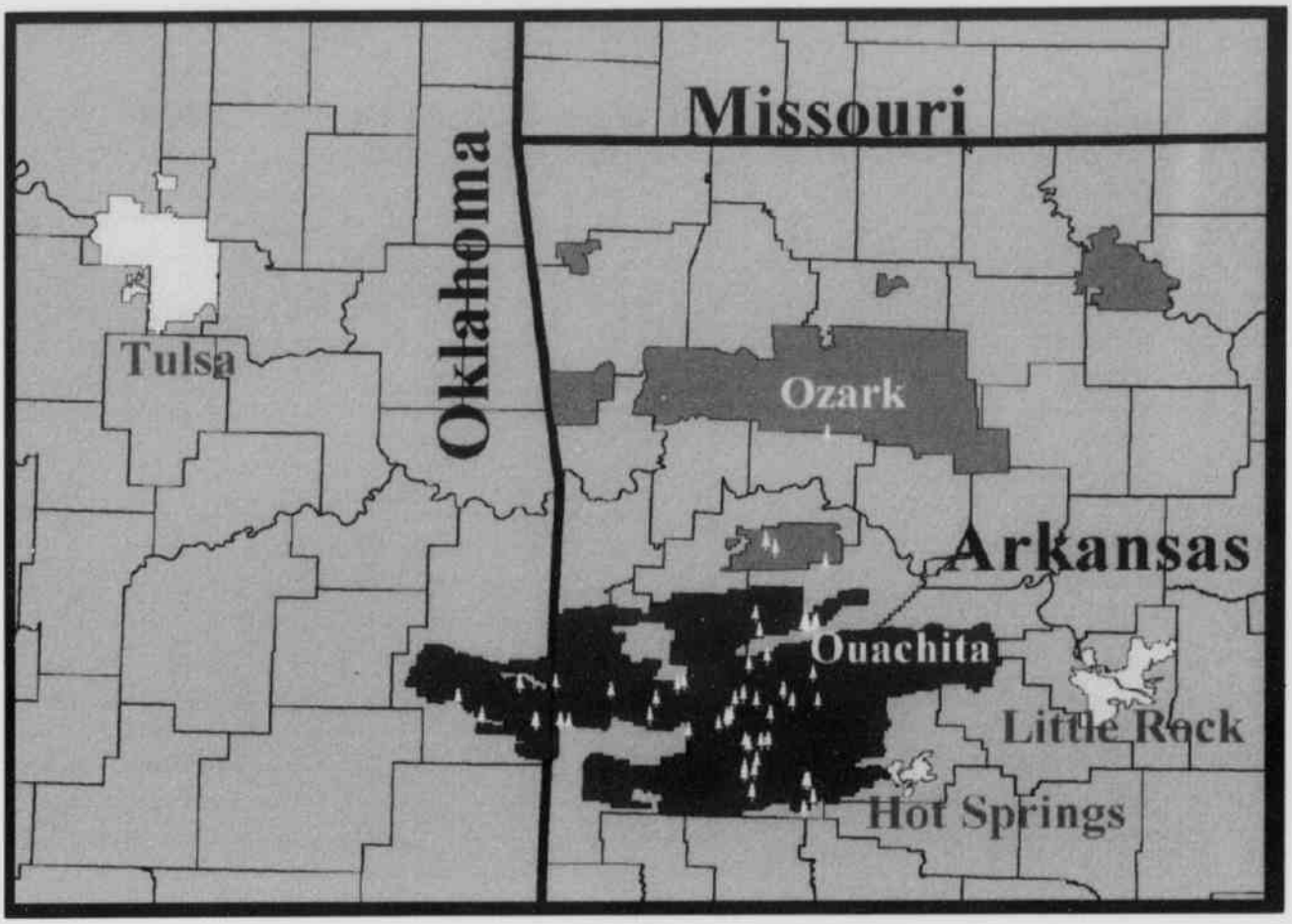

Fig. 1. Location of 52 Phase II stands in northwestern Arkansas and eastern Oklahoma.

Using the scanned and registered center aerial photo as a base layer for each stand, stand boundaries and greenbelts were delineated using "heads-up" digitizing in workstation ArcInfo. "Heads-up" is a digitizing method that captures spatial data by tracing over an image on the computer monitor. The stereo photography was utilized to insure the accuracy of boundary lines. Stand and greenbelt areas were calculated in acres and hectares using ArcView and then saved as attributes of each stand. GPSed silvicultural plot locations where imported into ArcView and overlayed on the aerial photo along with stand and greenbelt boundaries for each of the 52 Phase II stands (Fig. 2).

Developing a GIS Database.--Data submission, metadata, and data correction forms were designed and distributed to all researchers involved in the project. Compartment and stand numbers were selected to serve as primary database keys in the relational database model and link records to a central treatment database which contains coordinate information for each stand. Data distribution policies and procedures were established.

Because of the diversity of data types, from digital records to visual images, it was necessary to choose a software package that could easily display a wide range of data sources. ArcView GIS serves this purpose. Many types of data can be integrated and manipulated as various themes and projects. The ArcView interface can also be modified using Avenue* scripts so that researchers who have little experience with GIS software can easily interact with many layers of data. Avenue is an ArcView companion package that provides a programming language for customization and development of the ArcView interface. DBASE* was chosen as the relational database package because of its compatibility with ArcView and with most of the database and spreadsheet formats in which data are submitted.

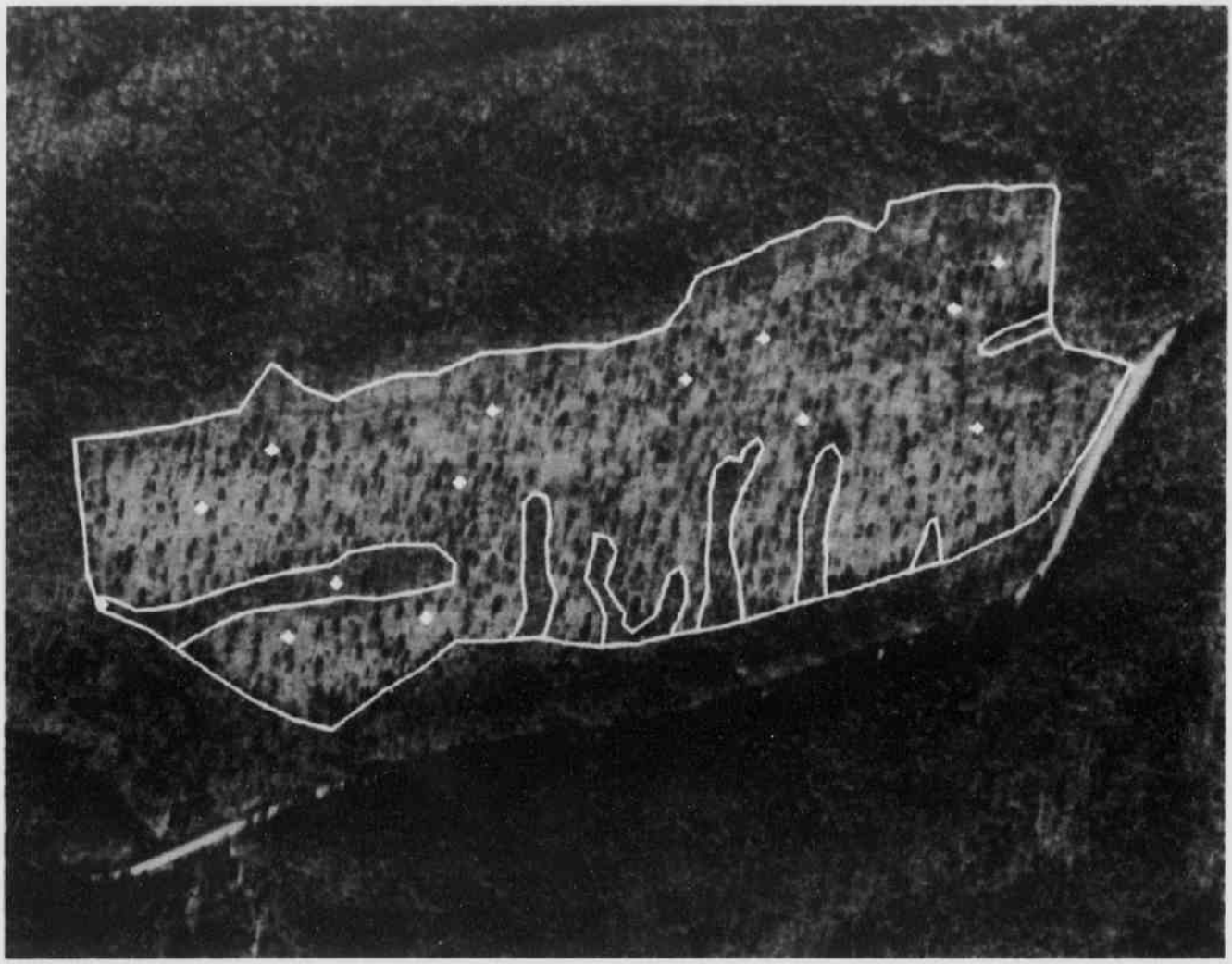

Fig. 2. Registered aerial photo of Stand 1036-17, pine/hardwood seed tree treatment, on the Oden Ranger District in the Ouachita National Forest, Yell County, Arkansas, with overlaying stand and greenbelt boundaries, and silvicultural plot locations.

Digital records from each research team member were brought into dBASE as separate files and linked by treatment, compartment, and stand number. Color slides, black and white photographs, and plot diagrams were converted to tiff images and "hot-linked" to the appropriate stands and/or plots using ArcView. Links between images and related theme features can be created so that clicking on a feature will display the linked image in a separate window. Stand maps and aerial photos were imported as image data and displayed as themes in ArcView projects. Tables, charts and analyses were also linked to stand data in ArcView. The linkage of spatial and attribute data in a GIS allows researchers to display, manipulate, query and analyze any data that can be referenced to a specific location.

Avenue scripts will be written to modify the ArcView interface for easier manipulation of research topics within the study. Icons will be incorporated into the Arc View button bar which correspond to specific data sets, such as wildlife, silviculture, visual quality, management economics, etc.

Data have been organized in an easily accessible manner. Both images and tabular data are stored on optical CD-ROM disks in a format that is accessible to many computer

platforms. Aerial photographs and printed ArcView layouts of stand and quad maps have been organized in notebooks for quick reference during the development of the project. Data and documentation submitted by researchers are arranged in a separate notebook.

A data dictionary accompanied the development of the database. The dictionary contains brief descriptions of projects and themes developed in ArcView and item definitions and coding descriptions for each variable represented in a theme. It also includes detailed variable definitions supplied by the researcher for each data file submitted.

Developing Researcher Access.--Several data access options are proposed. Access approval procedures were formulated by team members. Access on site in the Spatial Analysis Laboratory (SAL) in the School of Forest Resources will be the most direct route. Electronic access may be obtained over a high-speed modem or an internet connection to the World Wide Web (WWW). With an internet connection and any web browser that supports Java, remote PC clients will be able to access a PC in the SAL on which ArcView Internet Map Server is installed. This software is an extension to ArcView 3.0 and allows thousands of gigabytes of geographic information to be deployed and accessed via the Internet.

Discussion

Initiation of this data support system involved the development of a conceptual design which allows all research areas of the Phase II Ecosystem Management Project to be integrated into a spatial model. Remote sensing provided a base layer of photographs to which individual observations, statistics, tables, graphics, photographs, maps, etc. are linked based on common spatial coordinates. GIS provides access to all information layers and facilitates the evaluation of complex interactions using spatial statistics. When this database support system is fully developed, researchers will be able to investigate relationships between their data and that of others by overlaying themes and preforming spatial analysis procedures. Only by combining what we know about ecosystem components and ecosystem processes can we arrive at a more complete understanding of how ecosystems work and how they respond to disturbance (Larsen et al., 1997).

An ArcView/Avenue interface is being developed to allow easy access to the various components of each database topic. Electronic access will provide support and integration of all research activities. Researchers can not only share information resources, but can graphically visualize many facets of the forest ecosystem and its changes under various management strategies by investigating the spatial interrelationships. Researchers can also produce map products that clearly illustrate the effects and trade-offs of partial cutting methods on various commodity and non-commodity resources and values. The methodology used to develop and configure this very large, relational database into an easily accessible form usable in an interactive GIS environment should be transferable to many other areas of natural resource management.

* Use of registered trade names is solely for the reader's information and does not imply endorsement of the product.

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GENERAL NOTES

A Survey of Mollusca (Bivalvia: Unionacea) Inhabiting Myatt Creek, Fulton County, Arkansas

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Introduction

The past century has marked an alarming decline in native Unionacea populations in the United States. Their decline can be attributed to a variety of threats with habitat destruction being the single most important factor. Overutilization for commercial purposes, disease, predation, introduction of exotic species, pollution and hybridization are also threats. Unionacea are important indicators of aquatic environment health and are a major component of freshwater biodiversity (Williams et al., 1993). A description of the distribution of Unionacea in Myatt Creek will establish a basis for monitoring this resource in the study stream.

Myatt Creek originates on the Salem Plateau of the Ozark Mountains Physiographic Province in southern Missouri and drains southeasterly through Howell County, Missouri, and Fulton County, Arkansas, before reaching its confluence with the Spring River near Hardy. This physiographic province is composed of limestone and dolomite deposits of Ordovician origin (Croneis, 1930). Myatt Creek is a spring-fed, relatively pristine stream consisting of alternating pool-riffle biocies with gravel, bedrock and sand being the dominant substrates, in that order.

No studies pertaining specifically to the Unionacea of Myatt Creek have been conducted. Previous studies of this creek have superficially addressed fishes and aquatic insects (Beadles, 1972; Arkansas Game and Fish Commission, 1995). Gordon et al. (1980) and Rust (1993) have reported 45 species of Unionacea from the Spring River, compared to 19 found in Myatt Creek. The purposes of this paper are to present a species list, delineate distributions and report numerical standing crop data for each site.

Materials and Methods

During August and September, 1996, a 23.2 km section of Myatt Creek (Sites 1-11) was surveyed by canoe from a road crossing upstream of St. Hwy. 9 (SE 1/4 NE 1/4 S26, T21N, R7W) to the confluence of Wolf Creek with Myatt Creek (SE 1/4 NW 1/4 S 19, T20N, R5W). A second section (ΔU) was surveyed from approximately 0.8 km north to 0.8 km south of a road crossing in northern Fulton County (NW 1/4 SE 1/4 S14, T21N, R7W), and a third section (ΔL) from approximately 0.8 km upstream to the road crossing approximately 1.0 km north of St. Hwy. 9 (SE 1/4 NE 1/4 S26, T21N, R7W; Figure 1) was also sampled. Sampling methods included wading and snorkeling.

Generally, a concentration of shells was defined as an estimated area ≥ 5 m^2 with ≥ 3 live Unionacea or an area with numerous freshly dead shells. When a concentration was located, all specimens encountered were identified and returned to the substrate except for voucher specimens. Location, substrate type, water depth and any other pertinent site information were recorded. Oesch (1984) was used to identify specimens which could not be field identified. Voucher specimens are cataloged and housed in the Unionacea Collection of the Arkansas State University Museum of Zoology.

Site locations and a brief description of each are as follows:

1. Site 1. NW 1/4 S25, T21N, R7W. Shoal with water depths ranging from 0.2-1.0 m; gravel substrate.

2. Site 2. NW 1/4 SE 1/4 S25, T21N, R7W. Shallow riffle approximately 75 m below a large, deep pool; sand with gravel or bedrock substrate.

3. Site 3. SE 1/4 SW1/4 S30, T21N, R6W. Approximately 200 m downstream of the St. Hwy. 9 bridge. Site a shallow riffle; gravel/sand substrate.

4. Site 4. SW 1/4 SE 1/4 S30, T21N, R6W. Backwater area where spring-fed tributary enters Myatt Creek. Site considerably cooler than the main channel of Myatt Creek.

5. Site 5. S31, T21N, R6W. Approximately 0.8 km below Site 4. Shoal habitat.

6. Site 6. NE 1/4 SE 1/4 S31, T21N, R6W. Shoal divided by a small island at low water. Mussels located on the left-hand descending channel.

7. Site 7. NW 1/4 SE 1/4 S8, T20N, R6W. Shallow pool (< 1 m) between two riffles; substrate silt over sand with gravel; numerous lilypads present.

8. Site 8. NE 1/4 NE 1/4 S5, T20N, R6W. Second shoal upriver spring-fed creek and at confluence of creek and Myatt Creek.

9. Site 9. NE 1/4 SW 1/4 S3, T20N, R6W. Left-hand

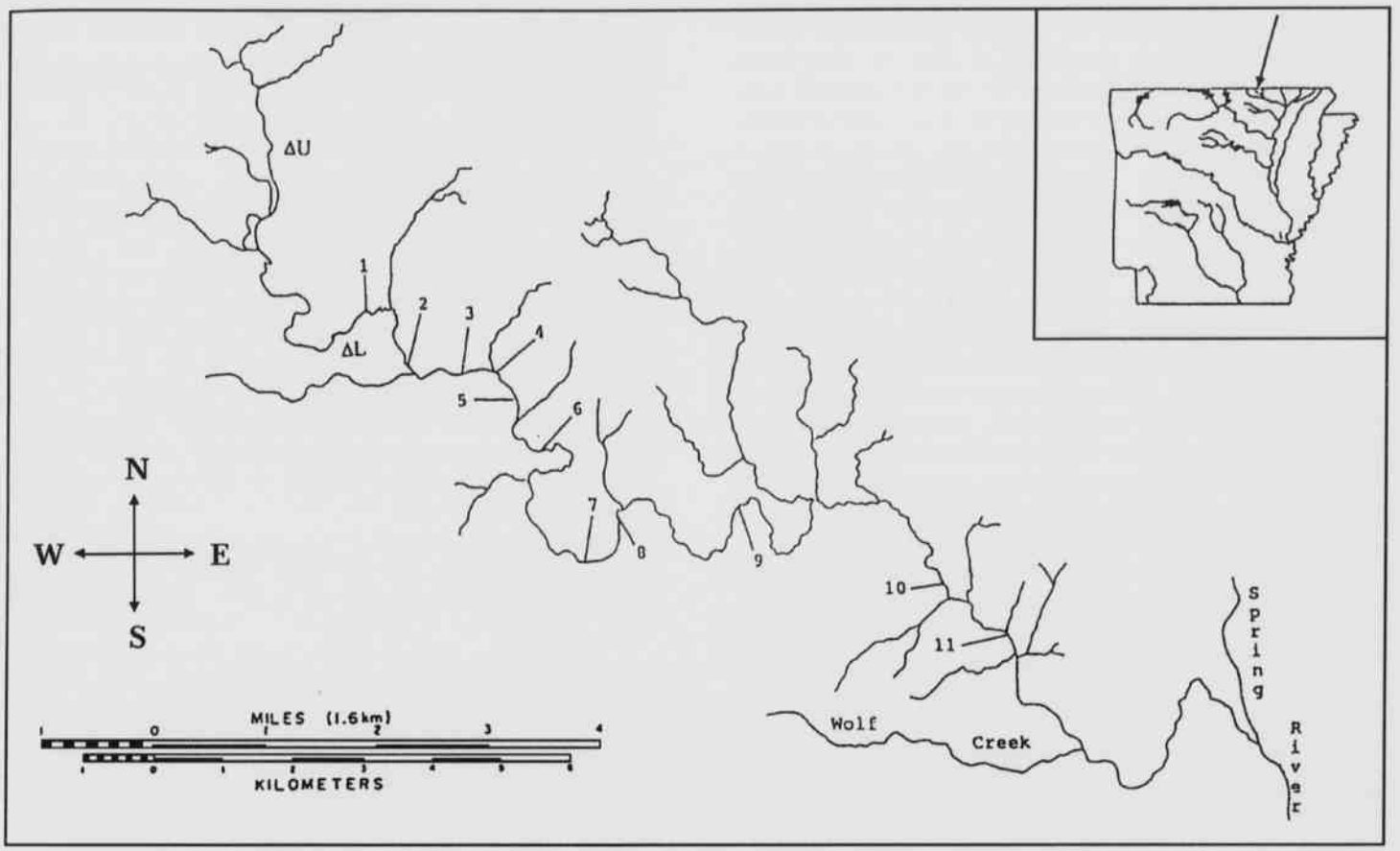

Fig. 1. Site locations for Unionacea from Myatt Creek, Fulton County, Arkansas, 1996. h = Road crossing, U = upper; L = Lower

descending bank in large pool approximately 300 m upstream from a bluff Similar to Site 7 except 0.1 m more silt at this site.

10. Site 10. SW 1/4 S12, T20N, R6W. Area at the head of 200 m long island.

11. Site 11. S13, T20N, R6W. Head of a shoal, substrate sand with gravel.

Results and Discussion

Nineteen species represented by 314 individuals (120 live individuals and 194 relicts) were collected during this survey. Of the 19 species, 10 were found only as relicts. Sites 2 and 7 yielded the greatest number of live individuals, while species richness was greatest at Sites 7, 8 and 10. *Ptychobranchus occidentalis* was the most abundant species (46.7 %), followed by *Venustaconcha ellipsiformis* (13.3 %) and *Lampsilis reeviana* (12.5 %).

Williams et al. (1993) listed seven Myatt Creek species as endangered (*Leptodea leptodon*), threatened (*Lampsilis reeviana* and *Ptychobranchus occidentalis*) or of special concern (*Alasmidonta viridis, Lampsilis cardium, Fusconaia ozarkensis* and *Venustaconcha ellipsiformis*). Myatt Creek is presently or historically within the range of three federally listed endangered species which were not collected in this survey: *Epioblasma florentina, Epioblasma turgidula* and *Lampsilis abrupta* (Harris and Gordon, 1987).

Unionacea were found in sparse concentrations (< 10/m^2) throughout Myatt Creek. Densities were the greatest at Sites 2 (1-5 mussels/m^2), 6 (3-10 mussels/m^2) and 7 (1-8 mussels/m^2). The areas of concentration at Sites 2, 6 and 7 were approximately 25-35 m^2, 15-25 m^2 and 35-45 m^2, respectively. The remaining sites all had mean densities of < 1 mussel/m^2 (Table 1). It was characteristic of all sites to find the shells located close to the shoreline and associated with aquatic vegetation.

No live specimens were found between Site 9 and 10, a distance of approximately 10 km. There were no signs of anthropogenic impacts, so more detailed studies may be needed to determine if this is a natural or anthropogenically induced absence. Site 10 had a concentration of relicts plus one live specimen of *Lampsilis reeviana.*

Two sites (6 and 11) had recently suffered massive die-offs. The die-off at Site 6 appeared to be a result of low water. Mussels at this site were located at the water's edge,

and low water appeared to threaten the survival of the remaining individuals. Mortality at Site 11 was 100%. Densities of 3-8 dead mussels/m^2 in the live position were found at this site, and there was no obvious cause of death.

Ptychobranchus occidentalis was the only species present at all sites. Three species, *Lampsilis cardium, Lampsilis reeviana* and *Venustaconcha ellipsiformis*, were present at ≥ 80% of the sites. The only trend the data show in Table I is an increasing number of relicts towards the mouth. Substrate and water levels were similar to those found in the upper reaches, so there is no immediately apparent cause for this trend.

No live specimens were found at either of the two road crossings. However, at the uppermost (northern most) road crossing, four relicts were found: *Lampsilis cardium* (1), *Lampsilis reeviana* (1) and *Ptychobranchus occidentalis* (2). The absence of living Unionacea at these sites is not immediately explainable. Anthropogenic influences do not appear to be extreme, nor is the habitat obviously unsuitable.

As a whole, those species of Unionacea collected in this survey are generally widespread in distribution (Oesch, 1984; Harris and Gordon, undated). Gordon et al. (1980) and Rust (1993) reported a greater diversity of Unionacea from the Spring River compared to that found in Myatt Creek. Spring River has a larger watershed and offers a greater diversity of habitats which accounts for a greater diversity of species. Five species found in this survey, *Alasmidonta viridis, Lampsilis siliquoidea, Leptodea leptodon, Venustaconcha ellipsiformis* and *Villosa iris,* were not reported for the Spring River by Rust (1993). Four of these species are generally restricted to stream headwaters, but *Lampsilis siliquoidea* is not (Oesch, 1984). Rust (1993) surveyed the lower 11 miles of the Spring River, which may account for the absence of *Lampsilis siliquoidea* from Rust's survey. Another explanation for the absence of this species from Rust's (1993) study is that it may be an uncommon species in the Spring River. With this species list and description of locations, a more comprehensive management plan can be designed for the sustained viability of the aquatic resources of Myatt Creek.

ACKNOWLEDGMENTS.—I am grateful to my father, Leonard Davidson, and my wife, Tamara Davidson, for their unyielding assistance in the field.

Table 1. Live/dead Unionacea collected from Myatt Creek, Fulton County, Arkansas, 1996.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Other
Amblema plicata							12/3	0/4	0/2	0/1		
Actinonaias ligamentina												R*
Alasmidonta viridis												R
Elliptio dilatata											0/3	
Fusconaia flava		1/0				2/0		0/2				
Fusconaia ozarkensis	0/2					0/2					0/1	
Lampsilis cardium		1/0	2/2	2/0	2/4	0/1	3/5	1/7	2/1	0/3	0/1	
Lampsilis reeviana		6/0	1/1	0/1	1/1	0/1	4/2	2/3		1/3		
Lampsilis siliquoidea							1/0	1/0		0/1		
Lasmigona costata					0/1	0/1	1/0	0/1	0/2	0/2		
Leptodea leptodon												R
Pleurobema coccineum						0/1						
Potamilus purpuratus											0/1	
Ptychobranchus occidentalis	0/4	20/1	3/6	5/2	0/5	10/19	10/4	7/8	1/1	0/7	0/16	
Quadrula pustulosa							0/2			0/1		
Strophitus undulatus		1/0					1/0			0/1		
Venustaconcha ellipsiformis		8/1	4/0	0/2		2/3	2/7	0/5		0/5	0/11	
Villosa iris				0/2						0/1		
Villosa lienosa									0/1			
Total	0/6	37/2	10/9	7/7	3/11	14/28	34/23	11/32	3/7	1/25	0/33	

*R = Relicts found at non-specified locations.

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Discovery of Fossil Cretaceous Bird in Southwest Arkansas

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During a field trip to the Middle Fork of Ozan Creek, Sec. 30, T. 10 S., R. 25 W., in Hempstead Co., AR in January, 1991, the junior author found a light brown, highly permineralized bone atop a gravel bar. The specimen, SAU 204, has been reposited with the Geology Department of Southern Arkansas University.

The specimen, 1.3 cm by 1.6 cm in cross-section, is 12.1 cm long and has a mass of 49.8 grams. It is interpreted as being part of the distal end of a left tarsometatarsus bone (Fig. 1) which preserves the articulation of only Digit IV. As Olsen (1979) states, "Perhaps no single bone is more readily recognized by workers with little or no experience in avian osteology than the uniquely structured tarsometatarsus. This is because of the distal end of the element, which terminates in three, more or less, distinct, rounded articular condyles or trochlea."

The geologic map of Arkansas (Haley, et al., 1976) assigns the bedrock at the discovery site to the Ozan formation of the late Taylor group (Campanian) in the Cretaceous period. The Ozan formation has been correlated with the Wolfe City Sand of Texas by Pessagno (1969).

Therefore, on the basis of the age of its source rocks and of its large size, SAU 204 is referred to the Cretaceous genus of toothed birds, *Hesperornis*, originally discovered by O.C. Marsh in 1870 and described in his monograph *Odontornithes* of 1880. Dr. Larry Martin of the University of Kansas concurs with this assignment, having compared SAU 204 directly with *Hesperornis*. Several species of *Hesperornis* have been erected for specimens recovered from sediments of the seaway that stretched from the Gulf of Mexico to the Arctic Ocean and covered southwestern Arkansas. SAU 204 constitutes the first known occurrence in Arkansas of this unusual lineage of birds. Martin (pers. comm., 1996) sees the specimen as the southernmost known individual of the genus and as one of the largest individuals recovered to date, possibly representing a new taxon.

The proportions of body parts in published figures such as Romer, 1964, and Feduccia, 1996, (both after Marsh, 1880) suggest that SAU 204 preserved about 75% of its original length. *Hesperornis* had tiny wings supported only by the remains of the humerus and relied on powerful feet for swimming. Its legs were oriented in such a fashion that the living creature probably could not stand upright, as seen in the standard reconstruction, but lay and moved upon the ground like a modern seal or sea lion (figure on page 160, Feduccia, 1996).

A typical Late Cretaceous marine fauna occurs with the *Hesperornis* specimen in the Ozan Creek gravel bars, but none of these elements have been found *in situ* to date. Shark teeth, perhaps referrable to *Squalicorex* and *Scapanorhynchus* (see Welton and Farish, 1993) have been found. Two calcified shark vertebrae 7.0 cm in diameter indicate how large these predators could grow. Sawfish rostral spines, genus *Ischyrhiza*, appear in some abundance, but no skate or ray teeth have been found, though they appear in the vicinity of Lake Millwood to the west of Ozan Creek. A single fragment of the mid-section of a fish fin spine 1.5 cm by 2.4 cm that is 7.5 cm long has been recovered. John G. Maisey, American Museum of Natural History, tentatively places it among the chimeroids because it has a concave posterior surface, it is straight and slender, and it is found in Late Cretaceous deposits (pers. comm., 1997).

Bony fish are represented by the small hooked teeth of *Stephanodus (Ancistrodon)*, by the fangs and jaw bones of the barracuda-like *Enchodus*, by the hypopleural bone at the base of the tail of *Protosphyraena* (J.D. Stewart, pers. comm., 1995) and by an elongated tooth plate of *Pycnodus*.

Mosasaur vertebrae with their distinctive ball and socket articulations are occasionally recovered. A jaw fragment with four teeth has been tentatively assigned to *Clidestes* by Gordon L. Bell, Jr., (pers. comm. 1996) based on its size, gracile proportions and lack of wear facets on the teeth. Dr. Willis Beene, D.D.S. of Magnolia, AR, attempted a dental X-ray examination of this specimen for un-erupted teeth, but results were inconclusive.

Four aceolous vertebrae of pliosaur marine reptiles are in hand, and one pliosaur leg bone, SAU 205, has been found and donated by Terry Sanders of Magnolia. The humerus (SAU 198) of a marine turtle with a carapace length estimated to exceed three feet was found in two pieces. It cannot belong to *Protostega* since its shaft is straight. Dr. Ed Hooks has noted its resemblance to *Toxochelyes* (pers. comm., 1995), but it is easily twice the size of the specimens in the Field Museum of Chicago.

We wish to gratefully acknowledge the assistance of Drs. Martin, Stuart, Bell and Massey in the identification of specimens. Ms. Stacy Sanders of the Southern Arkansas University art department prepared the figure.

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Fig. 1. Left tarsometatarsus bone (SAU 204).

Ground Flora Composition Following Harvesting of a Bottomland Hardwood Forest in the Mississippi River Batture Lands[1]

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Introduction

Ground flora is an important component of bottomland hardwood ecosystems (Harris and Gosselink, 1990). Herbaceous plants and small woody stems constitute important habitat components for various wildlife species such as white-tailed deer (*Odocoileus virginianus)*, wild turkey (*Meleagris gallopavo*), and small mammals (Brabander et al., 1985). This strata also provides browse, cover, and nesting sites for numerous species of insects, birds, fish, amphibians and reptiles. Alterations of the ground flora strata could have a significant impact on populations of these and other wildlife species (Bonham, 1989).

Reproduction cutting methods (i.e., clearcutting, seed-tree, shelterwood, or selection) are designed to regenerate a stand by natural or artificial means (Smith, 1986). Alterations of ground flora using silvicultural treatments and the degree of impact on floral and faunal communities in bottomland hardwood ecosystems are not well known (Lockaby and Stanturf, 1996). Therefore, the objective of this study was to evaluate ground flora composition following complete and partial harvesting in a bottomland hardwood ecosystem.

Materials and Methods

The study site was located on Pittman Island, Issaquena County, Mississippi on land owned by Anderson-Tully Company. This area was located inside the levee system of the Mississippi River (batture lands). The woody plant community consisted of riverfront hardwoods including sugarberry (*Celtis laevigata* Willd.), green ash (*Fraxinus pennsylvanica* Marsh.), and American elm (*Ulmus americana* L.). Other tree species included sycamore (*Platanus occidentalis* L.), sweet pecan (*Carya illinoensis* (Wang.) K. Koch), bitter pecan (*Carya aquatica* (Michx. f.) Nutt.), Nuttall oak (*Quercus nuttallii* Palmer), water oak (*Quercus nigra* L.), overcup oak (*Quercus lyrata* Walt.), boxelder (*Acer negundo* L.), red maple (*Acer rubrum* L.), common persimmon (*Diospyros virginiana* L.) and honey locust (*Gleditsia triacanthos* L.). Distribution of these species was based on physiographic conditions such as ridge/swale topography (Hodges and Switzer, 1979).

Permanent plots were installed during the summer of 1995 using a systematic plot design. Treatment plots were 20 ha in size and each treatment (clearcut, selection, and control) was replicated three times. Within each treatment sixteen 0.10-ha circular plots were installed. Eight of these plots were used to evaluate ground flora composition using a 1-m square plot located 5 m from plot center.

The study site was harvested during the winter of 1995-96. After harvesting, clearcuts were recentered and all remaining stems > 5 cm diameter at breast height (1.4 m above ground) were felled to establish a complete or biological clearcut. Selection cuts were harvested according to Anderson-Tully Company guidelines with approximately 50% of the basal area removed. Species favored to keep during marking included green ash, sweet pecan, Nuttall oak, and well-formed sugarberry.

Two herbaceous inventories were conducted during May and July 1996. These periods were separated by a flood that inundated the study site for approximately three weeks, followed by six weeks of dry weather. All plants within each of the 1-meter square plots were identified to species and classified as a forb, composite, legume, fungi, vine, or woody stem.

Calculations included Shannon-Weaver diversity indices (Shannon and Weaver, 1949) and importance values by species (sum of relative frequency and relative density). Sorenson's Community Similarity equation was also used to compare species composition between treatments (Mueller-Dombois and Ellenburg, 1974). Analysis-of-variance was used to determine if significant differences occurred between treatments ($P \leq .05$ level). Duncan's Multiple Range Test was used for mean separation (Little and Hills, 1974).

Nomenclature of tree species followed Duncan and Duncan (1988). Nomenclature of herbaceous plants fol-

lowed Smith (1988, 1994), Godfrey and Wooten (1981), and Radford et al. (1968).

Results

A total of 43 families and 67 species of herbaceous and woody plants was recorded during May and July 1996 (see Appendix). Of the 67 species recorded, 49% were forbs, 35% were woody and herbaceous vines, and 16% were woody stems. Many of these species were opportunistic annuals and perennials that quickly invade a site after a disturbance.

Species diversity of ground flora for May 1996 was greatest for the harvested treatments ($F = 10.05$, $P = 0.01$, $df = 8$; Table 1). No difference was found for species evenness ($F = 3.02$, $P = 0.12$, $df = 8$) or richness (number of species) between all treatments ($F = 2.84$, $P = 0.14$, $df = 8$) although controls were consistently lower in evenness (Table 1). Wild parsley (*Trepocarpus aethusae* Nutt.) had the highest mean importance value in selection and control treatments while stinging nettle (*Urtica chamaedryoides* Pursh) had the highest mean importance value in the clearcut treatment during May, 1996 (Table 2). Other species displaying high importance values were false nettle (*Boehmeria cylindrica* (L.) Sw.), sugarberry, and butterweed (*Senecio glabellus* Poir.) (Table 2). Similarity of community composition was greatest between the two harvesting treatments and lowest for the clearcut versus control treatments (Table 3).

Species diversity, evenness and richness all declined after inundation of the site during the 1996 growing season (July sampling; Table 3). No difference in diversity ($F = 2.61$, $P = 0.15$, $df = 8$) or evenness ($F = 3.67$, $P = 0.09$, $df = 8$) was found between treatments although selection cuts still had the highest mean diversity. Selection cuts also had greater richness than the other treatments ($F = 9.05$, $P = 0.02$, $df = 8$). The controls were consistently lower in diversity and evenness among all treatments (Table 1). With the exception of sugarberry seedlings and butterweed, species displaying high importance values in May were zero in July (Table 2). Two species of low importance in May had high mean importance values in July, buckwheat vine (*Brunnichia ovata* (Walt.) Shinners) and blackberry (*Rubus trivialis* Michx). These species, both herbaceous vines, were released after flood waters receded. Unlike the May sampling period, similarity of community composition was greatest for the selection and control treatments. The clearcut and control treatments remained the least similar (Table 3).

Discussion

Previous floristic studies in bottomland hardwoods have involved primarily tree species composition and successional relationships of woody plants (Carter et al., 1990; Wiseman, 1982). Baker and Hodges (in press) examined diversity of three canopy levels in clearcuts of different ages. They found that diversity stabilized at all canopy levels by year 35. Francis (1984) also found that herbaceous species abundance and above-ground biomass were higher in one-year-old clearcut areas, but declined after four years. Once openings are created, woody vines, shrubs, briers and herbaceous species quickly invade a site (Sharitz and Mitsch, 1993). In our study species composition one year

Table 1. Diversity, evenness, and richness by reproduction cutting method during the first growing season after harvest (1996) on Pittman Island, Issaquena County, MS.

	Reproduction Cutting Method		
	Clearcut	Selection	Control
May 1996			
Diversity	2.70a[1]	2.74a	2.34b
Evenness	0.81a	0.81a	0.74a
Richness	28a	30a	24a
July 1996			
Diversity	2.02a	2.31a	1.95a
Evenness	0.80a	0.76a	0.69a
Richness	13b	21a	Slab

[1]Numbers followed by the same letter within a row are not different ($P \leq 0.05$).

after harvest consisted of opportunistic annuals and perennials along with the release of perennial species that were on the site prior to harvest. Over time these species will probably decline in abundance and eventually be replaced by shrub and tree species (Baker and Hodges, in press).

Maintaining diversity in vegetation communities is an important aspect of bottomland hardwood ecosystems (Harris and Gosselink, 1990). Between 75 and 100 species of fish complete one or more of their life stages (egg, larvae, juvenile, and adult) in bottomland hardwood ecosystems by utilizing the ground flora. Species such as catfish (*Ictalurus* spp.), gar (*Atractosteus spatula* and *Lepisosteus* spp.), crappie (*Pomoxis* spp.), minnows and shiners (Cyprinidae) utilize ground vegetation for deposition of eggs and rearing of young (Killgore et al., 1994).

Having a variety of vegetation communities (trees, shrubs, and herbaceous plants) on a site is important for sustainability of resources such as wildlife habitat and water quality (Harris and Skoog, 1980). Assessment of ground flora composition after harvesting will aid in determining if suitable forage and nesting habitat is present for preferred wildlife species such as white-tailed deer, wild turkey and waterfowl. Assessment also has implications for determining the effects of harvesting on the regeneration and natural succession of bottomland hardwood ecosystems.

Conclusions

Growing season flooding along with harvesting practices are major factors affecting ground flora composition and diversity in the batture lands of the Mississippi River. Flood depth, duration and frequency are key factors that determine the kind of plant and animal species found in bottomland sites (Harris and Gosselink, 1990). Major disturbances, such as clearcutting, may revert a stand back to an earlier successional stage, therefore changing species composition of the site (Hanna, 1981). Natural succession is greatly influenced by differences in elevation and rate of deposition on bottomland hardwood ecosystems (Hodges, 1997). Increases in resources, such as light and nutrient availability, following a major disturbance result in a temporary increase in species diversity. Through succession these increases in ground flora composition will probably decline and advance into other seral stages.

ACKNOWLEDGMENTS.—We would like to acknowledge Anderson-Tully Company for the use of company lands in this study, the Arkansas Forest Resources Center for providing the initial funding for this study, and Dr. Philip Tappe for helpful comments in the development of this manuscript.

Table 2. Importance values (sum of relative frequency and relative density) for dominant ground flora by reproduction cutting method during the first growing season after harvest (1996) on Pittman Island, Issaquena County, MS.

Species	Reproduction Cutting Method		
	Clearcut	Selection	Control
May 1996			
Boehmeria cylindrica	75	57	13
Celtis laevigata	58	88	99
Senecio glabellus	81	63	22
Trepocarpus aethusae	73	111	149
Urtica chamaedryoides	106	109	76
July 1996			
Boehmeria cylindrica	0	0	0
Brunnichia ovata	67	84	111
Celtis laevigata	54	120	135
Rubus trivialis	80	99	96
Senecio glabellus	0	36	0
Trepocarpus aethusae	0	0	0
Urtica chamaedryoides	0	0	0

Table 3. Community Similarity Index for combinations of reproduction cutting methods during the first growing season after harvest (1996) on Pittman Island, Issaquena County, MS.

	Reproduction Cutting Method Combination		
Sampling Period	Clearcut/Selection	Clearcut/Control	Selection/Control
May 1996	0.71	0.42	0.59
July 1996	0.46	0.38	0.66

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Appendix. Species list for ground flora during the first growing season after harvest (1996) on Pittman Island, Issaquena County, MS.

Family	Scientific Name	Common Name
ACANTHACEAE	*Justicia ovata* (Walt.) Lindau var. *lanceolata* (Chapm.) R.W. Long	water willow
ACERACEAE	*Acer rubrum* L. var. *rubrum*	red maple
AMARANTHACEAE	*Amaranthus albus* L.	pigweed
ANACARDIACEAE	*Toxicodendron radicans* (L.) Kuntze	poison-ivy
APOCYNACEAE	*Trachelospermum difforme* (Walt.) Gray	climbing dogbane
AQUIFOLIACEAE	*Ilex decidua* Walt. var. *decidua*	possumhaw
ARISTOLOCHIACEAE	*Aristolochia serpentaria* L.	Virginia snakeroot
ASCLEPIADACEAE	*Gonolobus gonocarpus* (Walt.) Perry	angle-pod
BIGNONIACEAE	*Bignonia capreolata* L.	crossvine
	Campsis radicans (L.) Seem.	trumpet creeper
BORAGINACEAE	*Heliotropium indicum* L.	Indian helitrope
CHENOPODIACEAE	*Chenopodium album* L. var. *album*	pigweed
COMMELINACEAE	*Commelina virginica* L.	day-flower
COMPOSITAE	*Senecio glabellus* Poir.	butterweed
	Solidago canadensis L.	goldenrod
CORNACEAE	*Cornus drummondii*Meyer	swamp dogwood
CRUCIFERAE	*Capsella bursa-pastoris* (L.) Medic.	Shepard's purse
	Cardamine hirsuta L.	cress
CUCURBITACEAE	*Melothria pendula* L.	creeping cucumber
CYPERACEAE	*Carex cherokeensis* Schwein.	Cherokee sedge
	C. crus-corvi Shuttlw. ex Kuntze	sedge
EBENACEAE	*Diospyros virginiana* L.	common persimmon
E UPH ORBIACEAE	*Acalypha rhomboidea* Raf.	three-seeded mercury
FAGACEAE	*Quercus nigra* L.	water oak
FUMARIACEAE	*Corydalis flavula* (Raf.) DC.	pale corydalis
GRAMINEAE	*Leptochloa filiformis* (Lam.) Beauv.	sprangletop
	Panicum capillare L. var. *capillare*	panic grass
	P. laxiflorum Lam.	panic grass
JUGLANDACEAE	*Carya illinoensis* (Wang.) K. Koch	sweet pecan
LABIATAE	*Teucrium canadense* L. var. *canadense*	wood sage
LEGUMINOSAE	*Gleditsia triacanthos* L.	honey locust
	Vicia sativa L.	common vetch
	V. tetrasperma (L.) Moench	common vetch
LILIACEAE	*Smilax bona-nox* L.	greenbriar
	S. rotundifolia L.	greenbriar
	S. tamnoides L. var. hispida (Muhl.) Fern.	greenbriar
LOGANIACEAE	*Gelsemium sempervirens* (L.) Jaume St. -Hill	yellow jessimine
MENISPERMACEAE	*Cocculus carolinus* (L.) DC.	Carolina moonseed
OLEACEAE	*Forestiera acuminata* (Michx.) Poir.	swamp privet
	Fraxinus pennsylvanica Marsh.	green ash
OXALIDACEAE	*Oxalis dillenii* Jacq.	wood sorrell
PASSIFLORACEAE	*Passiflora lutea* L.	yellow passion flower
PHYTOLACCACEAE	*Phytolacca americana* L.	pokeweed
POLYGONACEAE	*Brunnichia ovata* (Walt.) Shinners	buckwheatvine
	Polygonum Dunctatum Ell.	smartweed
	P. tenue Michx.	smartweed
	P. virginianum L.	jumpseed
RHAMNACEAE	*Berchemia scandens* (Hill) K. Koch	rattan vine
ROSACEAE	*Rubus flagellaris* Willd.	dewberry
	R. trivialis Michx.	blackberry
RUBIACEAE	*Spermacoce glabra* Michx.	smooth buttonweed
	Galium aparine L.	bedstraw
SOLANACEAE	*Physalis angulata* L.	ground cherry
	P. Dubescens L.	ground cherry
ULMACEAE	*Ulmus americana* L.	American elm
	Celtis laevigata Willd.	sugarberry
UMBELLIFERAE	*Trepocarpus aethusae* Nutt.	parsely
	Sanicula canadensis L.	black snakeroot
URTICACEAE	*Urtica chamaedryoides* L.	stinging nettle
	Boehmeria cylindrica (L.) Sw.	false nettle
VALERIANACEAE	*Valerianella radiata* (L.) Dufr.	corn salad
VIOLACEAE	*Viola sororia* Willd. var. *sororia*	violet
VITACEAE	*Ampelopsis arborea* (L.) Koehne	pepper vine
	Parthenocissus auinauefolia (L.) Planchon	Virginia creeper
	Vitis aestivalis Michx.	summer grape
	V. mustanzensis Buckl.	grape
	V. rotundifolia Michx.	muscadine

New Records for the Distribution of an Unusual Liverwort, *Petalophyllum ralfsii* (Fossombroniaceae)

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Petalophyllum ralfsii (Wils.) Nees & Gottsche is considered a rare plant, known in North America only from Texas, Louisiana, and Arkansas (Schuster, The Hepaticae and Anthocerotae of North America, vol. 5, pp. 423-430, 1992). In Arkansas it was previously known only in Union County. We report it from eleven additional Arkansas counties and add it to the list of small plants found in rural cemeteries and churchyards. This study was partly funded by a faculty research grant from Henderson State University for the study of Arkansas bryophytes.

In March 1994 while searching for pteridophytes, Marsh found an unfamiliar liverwort in the Marks Historical Cemetery in Cleveland County north of New Edinburg but failed to collect any specimens of it. Later notice of an illustration (Conard and Redfearn, How to know the mosses and liverworts, 2nd ed., Wm. C. Brown Co. p. 276, 1979) suggested the plant might be *P. ralfsii*. When Marsh became more interested in the Fossombroniaceae in 1996, study of a detailed account of *Petalophyllum* (Schuster, ibid.) convinced that he had indeed seen *P. ralfsii*. Early in 1997 he proposed a search for the species to several students and associates.

On January 19, 1997, Marsh and Golden made a search of the Marks Cemetery and Golden found a small population (*Golden 74*). On the same day a second Cleveland County population was found in Mosley Cemetery east of New Edinburg (*Marsh 8962*). Vouchers were sent to Southern Illinois University at Carbondale for confirmation of identification.

The search team discovered a series of additional populations: Bethel Cemetery east of Okolona, Clark Co., Jan. 26, *Marsh 8968*; Smyrna Methodist Church north of Okolona, Clark Co., Jan. 26, *Golden 75*; Antioch Cemetery southwest of Social Hill, Hot Spring Co., Jan. 28, *Crank 97001*; Camp Ebenezer north of Center Point, Howard Co., Feb. 2, *Nunley 97008*; Ebenezer Methodist Church north of Village, Columbia Co., Feb. 2, *McDaniel 454*; Poyen Cemetery, Grant Co., Feb 8, *McDaniel 458*; Rosston Cemetery, Nevada Co., Feb. 22, *Golden 84*; Bell Chapel southeast of Bragg City, Ouachita Co., Feb. 23, *Golden 85*; Shiloh Union Baptist Church northeast of Stamps, Lafayette Co., Apr. 12, *Marsh 9015*; Centerpoint Cemetery south of Dalark, Dallas Co., Apr. 13, *Golden 112*; Calaway Cemetery south of Thornton, Calhoun Co., Apr. 13, *Golden 114*.

Although *P. ralfsii* has been considered a Gulf Coastal Plain species, the Hot Spring Co. site is in the edge of the Interior Highlands. Two of our Coastal Plain sites are in the Southwestern Arkansas Cretaceous area. The soils of all the sites range from fine sandy loam to gravelly loam and are mostly well drained. Grass cover ranges from sparse to dense, often obscuring the small *Petalophyllum* plants which are usually less than a centimeter long. The populations ranged in size from only a few plants to more than one hundred individuals. In all stands *P. ralfsii* was less abundant than the characteristic associated species. Among the associates in the populations we studied, *Asterella tenella* was almost always present and was the best indicator of spots most likely to also have *P. ralfsii*. *Lepuropetalon spathulatum*, "Little People," was usually immediately associated or nearby. There was usually one or more species of *Fossombronia*, *F. foveolata*, *F. brasiliensis*, and perhaps a third entity, which is being evaluated by Ray Stotler and Barbara Crandall-Stotler (Southern Illinois University at Carbondale) who visited the Colombia Co. and Nevada Co. sites in March. Other common associates of *P. ralfsii* were *Ophioglossum crotolophoroides*, *O. nudicaule*, *Botrychium lunarioides*, and a number of moss species.

The three areas of known occurrence (southwestern Arkansas, central Louisiana, central Texas) of *P. ralfsii* in North America are rather widely separated. Are these truly disjunct areas or are they connected by a series of presently unknown populations? If they are disjunctive, do they represent three different geographical races with different ecological requirements? Rural cemeteries and church yards are a newly-known habitat for this species, but the number of populations we have found in a short period of time suggests that this may be its most common habitat.

New Studies of Polyfuran and Polymers of 3-Substituted Furan Rings

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Polyfuran, polypyrrole, and polythiophene are conjugated planar aromatic polymers that have shown a great deal of promise as conductive polymers (Lee and Kertesz, 1988; Colon and Kwiatkowski, 1990; Sabbatini and Zambonin, 1992; Hong and Marynick, 1992; Christensen et al., 1994). Very little research on polyfuran (Fig. 1) has been reported in the literature, compared to that on polypyrrole and polythiophene. The synthesis of polyfuran by electrochemical means was reported in 1990 (Nessakh et al., 1990). However, the electrochemical formation of polyfuran requires an applied potential of greater than 3 volts. This potential was found to be too oxidizing for the resulting polymer, which decomposes oxidatively. Later, it was found that electrochemical polymerization of the tetramer, terfuran, could be accomplished at a lower potential, ~0.75 volt (Hernandev et al., 1993). Unlike polypyrrole and polythiophene, very little has been reported in the literature about chemical preparations of polyfuran (Baker et al., 1994; Robitaille and Leclerc, 1994; Murao, 1990). Out of these three polymers, polyfuran appears to be the most chemically unstable with respect to ring opening by nucleophilic reagents, especially in the oxidized, doped state. A potential method of ring opening would be nucleophilic attack on the α-carbons by water.

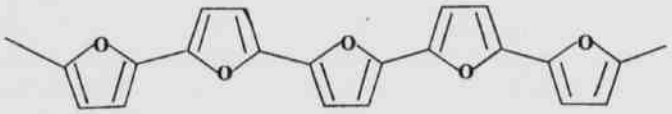

Fig. 1. Polyfuran in "head to tail" arrangement.

In this note we report the chemical synthesis of polyfuran starting from the monomer. Initially chemical polymerization of furan was attempted using a number of oxidizing agents. Several experiments using O_2 and a Ni catalyst, ferric chloride, and potassium ferricyanide resulted in only aliphatic products. An oxidizing agent which has proven more successful is pyridinium chlorochromate (PCC). Several polymers of furan have been synthesized with PCC under a variety of conditions. While these polymers were proven to be primarily aromatic (as shown by ^{1}H NMR), some still had evidence of ring opening (as shown in the IR spectra by OH stretch at 3200 - 3500 cm^{-1}). The conditions which provided the least amount of ring opening (less than 5% aliphatic) are described as follows. Inhibitor free furan (60 mL) was added to 40 mL of a 0.29 M PCC solution in dry tetrahydrofuran (THF). The mixture was stirred at room temperature for 12 hours, resulting in a black, tar-like precipitant. Excess furan and THF were evaporated under reduced pressure. To remove the PCC from the product, the precipitant was repeatedly dissolved in dimethyl sulfoxide (DMSO), reprecipitated by the addition of THF and then decanted. This reprecipitation process was repeated until essentially all the PCC was recovered from the decanted THF (a minimum of four times). The product was then washed three times with THF and dried under vacuum. (Average yield = 4.2±0.5 grams).

The product was characterized by UV, IR, NMR, and ESR spectroscopy. The UV-visible spectra of the polyfuran product exhibits a broad absorption band with a maximum of 469 nm. This broad absorption band, from 430 nm to 540 nm (2.9 eV - 2.3 eV) corresponds to a $\pi \rightarrow \pi^*$ transition. The infrared spectra of the polyfuran product has some bands that are characteristics of the monomer (1585, 1530, 1383, 1200, 1160, 1060, 890, and 730 cm^{-1}). Additional bands shown in the IR of the polymer at 1165, 1090, and 1030 were attributed to C-H bending and stretching, and a band at 640 cm^{-1} was attributed to aromatic C-H out of plane bending. One band at 789 cm^{-1} can probably be attributed to the head to tail coupling (Fig. 1) of the carbon backbone. These data are consistent with IR data reported on polyfuran produced by electrochemical means (Hernandev et al., 1993). The room temperature ESR spectra of the polyfuran product exhibits a Gaussian signal (ΔH_{pp} = 0.8G) with a spin concentration of 8.6 x 10^{19} spins/mole. The species responsible for the ESR signal is most likely unpaired electrons in the conjugated π system, which may come from defects in the polymer.

The chemical instability of polyfuran created problems during attempts to derivatize the polyfuran for cross-linking. Derivatization attempts using chlorosulfonic acid (as used in procedures for derivatization of polypyrrole and polythiophene) proved to be extremely unsuccessful. In each attempt, the polymer was broken down into small, ether soluble fragments. Similar depolymerization problems with

functionalizing furan based polymers has been reported in the literature (Viswanathan et al., 1993). Therefore, we concentrated on derivatizing the monomer prior to polymerization.

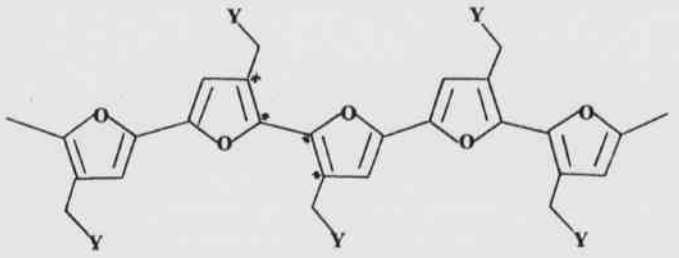

Fig. 2. Y = -OH, =O, -O-C-CH_3, -SH
(-O-C(=O)-CH_3)

Our most recent work has focused on an effort to determine an appropriate 3-substituted furan monomer which could be polymerized into a conjugated polymer that would maintain the co-planarity of the furan rings. A molecular modeling study, using a PCMODEL program (Serena Software), was conducted of polymers produced from several monomers (furan, 3-furan methanol, 3-furan methanal, 3-furan methanol acetate, and 3-furan mercaptomethanol - Fig. 2). Structures of 4 to 20 monomeric units were examined to determine the most stable configuration and degree of co-planarity. The structures were energy minimized via molecular mechanics, and dihedral rotation (around the four atoms indicated in bold on Fig. 2) vs energy plots were produced. For each of the monomers the head to tail arrangement with the 3-substituent group pointed in opposite directions (as shown in Fig. 2) represented the lowest energy structure. Chains of polyfuran in head to head arrangements of six or more monomers acquire significant energy increases in the torsional angle from the curvature. Modeling of longer chains of polyfuran (30 to 50 monomers) shows that the torsional strain is relieved somewhat when an occasional monomer inverts from the head to tail arrangement during minimization. Modeling studies of polymers of 3-furan methanol showed a dramatic loss in coplanarity in chains containing 4 to 10 monomers. The twisting of the molecule, due to hydrogen bonding of the hydroxy groups, greatly disrupts the planarity of the pi system. While dimers of 3-furan methanol show coplanarity, tetramers have about a 30° rotation from planarity. The torsional angle increases with increasing polymer size. The models of 3-furan methanol acetate show very little planarity; however, models of 3-furan mercaptomethanol show very good coplanarity of the rings even in tetramers or larger. The dihedral rotation plots (atoms indicated in Fig. 2) of 3-furan mercaptomethanol show extremely low energy minima (< 64.5) at 180°. The hydrogen bonding of 3-furan mercaptomethanol is much less extensive than that seen in 3-furan methanol; therefore, coplanarity is much more conserved. Synthesis of the monomer, chemical polymerization of studies of the unprotected monomer, as well as molecular modeling studies of 3-furan mercaptomethanol with a sulfhydryl protecting group (Bodanszky and Bodansky, 1989) recommend either a S-ethylcarbamoyl or a S-acetamidomethyl protecting group) will be forthcoming.

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Rediscovery of *Parnassia asarifolia* Vent. (Parnassiaceae) in Arkansas

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This study was undertaken when McDaniel (October 1, 1996) found a *Parnassia* in Hot Spring County (approximately 5 miles southeast of Donaldson) with characteristics not matching those of *P. grandifolia*, the only species listed for Arkansas by Smith (1988, 1994). Use of the keys and descriptions in Correll and Johnston (1979) and Radford et al. (1968) indicated that the species was *Parnassia asarifolia* Vent. Duplicate vouchers were sent to Dr. E. B. Smith, curator of the herbarium at the University of Arkansas at Fayetteville, who confirmed the identification.

A search of the Henderson State University herbarium revealed that two specimens of *P. asarifolia* had been collected from another location in Hot Spring County (approximately one mile north of Perla) in October 1991 by P. X. Majestyk and misidentified as *P. grandifolia*. A visit was made to confirm that the population was still in existence. McDaniel discovered a third population in Hot Spring County (near Central) on September 3, 1997.

The location of the three *P. asarifolia* sites is on the Gulf Coastal Plain, while the range of *P. grandifolia* indicated by Smith (1988) and Hunter (1992) is in the Interior Highland. Crank suggested a *P. grandifolia* population in Montgomery County as a convenient site for comparison of the two species and their respective communities.

P. asarifolia has several readily visible morphological features that help distinguish it from *P. grandifolia*. The leaf blades of *P. grandifolia* are ovate to oblong while those of *P. asarifolia* are reniform, hence one of its common names, kidneyleaf grass-of-Parnassus (we prefer ginger-leaved bog-star). Two floral characters easily separate the two species. In *P. asarifolia* the petals are clawed and have staminodia which are shorter than or equal to the fertile stamens. *P. grandifolia* does not have clawed petals and its staminodia are considerably longer than the fertile stamens.

The three known Arkansas communities in which this rare plant thrives are wet, partially shaded and acidic. The Donaldson population is in a hillside seep and the Perla population is in boggy woodland in a narrow valley. The Central population includes a stand near a stream in a wooded valley and a smaller patch in a seep on a wooded slope. These two stands are separated by a gas line right-of-way.

Overstory trees common to these sites include loblolly pine, red maple, American holly, and sweet gum. Characteristic of the understory are umbrella magnolia, farkleberry, common alder, laurel greenbrier, and wax-myrtle. In the immediate vicinity of the bog-star plants, sphagnum is the dominant ground cover. Other associates include violets, cinnamon fern, royal fern, lady fern, netted chain fern, and the liverwort *Pallavicinia lyellii*. Sweetbay magnolia is conspicuous at the Perla site and Central site but not seen at the Donaldson site. Red chokeberry is abundant at the Perla site.

The habitat of *P. grandifolia* showed a strikingly different aspect than that of *P. asarifolia*. The plant community investigated lies alongside a well-shaded, rocky, mountain stream. *P. grandifolia* was found growing along the bank of the stream, but no individuals were found to be growing in the water. Overstory trees of this community included sweet gum, sycamore, and winged elm. In the understory were umbrella magnolia, flowering dogwood, witch-hazel, and common alder. Close associates of *P. grandifolia* were crested iris, ragwort, wood betony, ironweed, and Christmas fern.

At the time of our study *P. asarifolia* was not included in the Arkansas flora by Smith (1988, 1994), and Arkansas was not included in the range of *P. asarifolia* given by many of the standard regional manuals (Correll and Correll, 1975; Correll and Johnston, 1979; Godfrey and Wooten, 1981; Radford et al., 1968). Spongberg (1972) specifically included Arkansas in the range of *P. grandifolia*, but made no mention of Arkansas in the range given for *P. asarifolia*. The only sources we found which included Arkansas in the range of this species were Gleason and Cronquist (1963) and Gleason (1968).

Mr. Bill Shepherd of the Arkansas Natural Heritage Commission provided us with an unpublished document from the ANHC files which listed *Parnassia* specimens examined by R. B. Phillips for his dissertation completed in 1982. One Arkansas specimen of *P. asarifolia* was included, collected on April 18, 1926, by E.J. Palmer (*29699*) in Hot Spring County and labeled "near Malvern, wet shaded banks about spring," The list indicated that the specimen was at the herbarium of the New York Botanical Garden. Communication with NYBG informed us that the specimen was a single sheet of four immature plants. Our examination of the paper by Phillips (1982) provided no additional information on Arkansas material.

We believe that the Perla site may very well be the location where Palmer first found *P. asarifolia* in Arkansas. In

any case, we now have the presence of *P. asarifolia* in the Arkansas flora fully documented, and voucher specimens filed in the herbaria of the University of Arkansas at Fayetteville and Henderson State University.

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Presence of Hantavirus in Small Mammals of the Ouachita Mountains

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In 1993, an outbreak of human hantavirus pulmonary syndrome (HPS) occurred in the southwestern United States causing severe pulmonary disfunction and death among most of those infected. Shortly after the outbreak, the causative agent was identified as the Sin Nombre virus (SNV), a virus of the genus *Hantavirus*. Several hantaviruses have since been identified in North America and rodents have been identified as the hosts of these hantaviruses. Each hantavirus has been associated with a single primary host species in which it causes a chronic, persistent infection involving the shedding of virus in saliva, feces, and urine (LeDuc, 1987). Infection to humans is thought to be from inhalation of aerosolized virus (breathing of small particles such as dust from feces, blood, or urine) (Tsai, 1987). However, rodent bites or direct contact with broken skin or mucus membranes also are potential sources of infection (Nuzum et al., 1988).

The deer mouse (*Peromyscus maniculatus*) was found to be the primary reservoir of SNV, however, other small mammals have been found to carry antibodies for this and other potentially deadly hantaviruses (Childs et al., 1994). It is not known whether human infection can occur from non-primary host species which carry antibodies for the virus (Centers for Disease Control and Prevention, pers. comm.). The Blackwater Creek Canal virus (hosted by the cotton rat *Sigmodon hispidus*), Bayou virus (hosted by the rice rat *Oryzomys palustris*), and SNV have all been associated with human HPS, however, SNV has caused the most human mortality (Childs et al., 1995). The Prospect Hill virus (hosted by the pine vole *Microtis pennsylvanicus*) and the El Moro Canyon virus (hosted by the western harvest mouse *Reithrodontomys megalotis*) have not been associated with any reported cases of HPS, however, little is known about the potential risks of these and other yet undiscovered hantaviruses (Childs et al., 1995).

Cases of SNV-induced HPS have been reported from surrounding states including Texas, Louisiana, Oklahoma, and Kansas but none has been documented in Arkansas, and the risk of infection is unknown (Centers for Disease Control and Prevention, 1997). Research conducted by the USDA Forest Service Southern Research Station, in conjunction with state and private cooperators, involves extensive small mammal trapping and handling in Arkansas. Because two of the first 102 recognized cases of SNV-induced HPS in the United States occurred in field biologists with a history of contact with rodents (Mills et al., 1995), we sought to determine the incidence of hantavirus antibodies in Arkansas small mammals to ascertain potential risks for human hantavirus infection.

Small mammals were captured in kill traps at 19 locations in Garland and Saline counties within the Ouachita Mountains of west-central Arkansas in 1994 and 1995. These mammals were collected primarily in forested riparian areas on Weyerhaeuser Company lands. A total of 520 small mammals was sent to the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia for testing. Each mammal was tested for the presence of hantavirus antibodies using laboratory methods described in detail by Mills et al. (1997). Assays used by the CDC would detect, but not distinguish among, infections caused by other North American hantaviruses. Results were forwarded to us from the Arkansas Department of Health.

Of the 520 small mammals submitted for analysis, 4 were reactive for hantavirus antibodies (Table 1), indicating they either carried or had been exposed to SNV or one of the other North American hantaviruses. Although the deer mouse is thought to be the primary host of SNV, our sample included only two of this species. Nevertheless, one of the two deer mice we submitted was positive. SNV infection rates in deer mice have ranged from 11% to 30% of individuals in the American Southwest (Mills et al., 1997). Two cases of HPS that have occurred outside the range of the deer mouse have been linked to the whitefooted mouse (*Peromyscus leucopus*), indicating the white-footed mouse may be a potential vector for SNV or another deadly hantavirus (Mills et al., 1997). In our sample, the cotton mouse (*Peromyscus gossypinus*) and the white-footed mouse were lumped into a single group (*Peromyscus* spp.) because of difficulties in distinguishing the two species. However, no *Peromyscus* other than *maniculatus* were positive in our sample. One non-rodent species, the short-tailed shrew (*Blarina carolinensis*) was found to be positive.

For all species combined, the infection rate was 0.8%. This is probably a low estimate of hantavirus infection rates among Ouachita small mammals because of the low numbers of deer mice included in our sample. Nevertheless, it

does present the first evidence that SNV or another closely-related hantavirus is present among small mammals in Arkansas and presents the first data indicating the presence of hantavirus antibodies in the golden mouse (*Ochrotomys nutalli*). Although laboratory tests did not discern SNV from other hantaviruses, three of the five hantaviruses that occur in North America are known to cause HPS and other hantaviruses may exist that have not yet been identified. Further testing needs to be done to determine exact hantavirus infection levels as well as tests to determine which hantaviruses are present and what species, if any, may be primary vectors for these viruses in Arkansas.

Table 1. Numbers of small mammals tested for hantavirus antibodies, numbers positive, and percent positive, collected in the Ouachita Mountains of Arkansas, 1994-1995.

Species	Number tested	Number positive	Percent positive
Blarina carolinensis	134	1	0.7
Glaucomys volans	10	0	0.0
Microtus pinetorum	11	0	0.0
Neotoma floridana	6	0	0.0
Ochrotomys nuttalli	285	2	0.7
Oryzomys palustris	1	0	0.0
Peromyscus attwateri	5	0	0.0
Peromyscus maniculatus	2	1	50.0
Peromyscus spp.	43	0	0.0
Reithrodontomys fulvescens	20	0	0.0
Sylvilagus floridanus	1	0	0.0
Tamias striatus	3	0	0.0
All species	520	4	0.8

Concern for hantavirus among mammalogists in Arkansas ranges from no concern to extreme caution in dealing with small mammals (pers. comms). Since 1994, the USDA Forest Service Southern Research Station, Weyerhaeuser Company, and the University of Arkansas at Monticello's School of Forest Resources have been using the CDC's precautionary interim guidelines (Centers for Disease Control and Prevention, 1993) to reduce risk of possible hantavirus exposure. These guidelines include wearing respirators and surgical gloves when handling small mammals and sterilizing equipment that has come in contact with small mammals. Although there have been no documented cases of HPS in Arkansas and biologists have been handling small mammals in Arkansas for years, our findings indicate that hantaviruses are present in at least Garland and Saline counties. Given the high mortality rate associated with HPS, other biologists may want to review safety procedures (Mills et al., 1995).

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Reductive Dechlorination of a 2-Chloronicotinic Acid Under Finkelstein Conditions

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We reported previously the preparation of 5-fluoro-6-iodonicotinic acid and 5-bromo-6-iodonicotinic acid (Setliff, F., J. Chem. Eng. Data 18: 449-450, 1973) as well as 5-chloro-6-iodonicotinic acid (Setliff, F., J. Chem. Eng. Data 21: 246-247, 1976) by the Finkelstein Reaction (Klingsberg, E., J. Am. Chem. Soc. 72:1031, 1950). The process involves nucleophilic displacement of chloride by iodide (as sodium or potassium iodide) in refluxing acetone or methyl ethyl ketone (MEK), and the reaction is driven by the insolubility of the resultant sodium or potassium chloride in the ketone solvent. The aforementioned 5-halo-6-iodonicotinic acids were thus generated from their respective 6-chloro derivatives in acceptable yields. Although these reactions are presumably catalyzed by autoprotonation of the ring nitrogen, it was found that our conversions proceeded more efficiently when a small amount of hydroiodic acid was added. The electron withdrawing carboxyl group para to the 6-chloro, together with the halogen in the five position, and the protonated ring nitrogen all serve to activate the 6-chloro for nucleophilic displacement by iodide.

Reasoning that an ortho carboxyl group and a para bromo should also promote chloride displacement, we attempted the preparation of 5-bromo-2-iodonicotinic acid from 5-bromo-2-chloronicotinic acid by the Finkelstein technique, but the expected bromoiodoacid was not formed. Surprisingly, 5-bromonicotinic acid was the only product isolated, and the reaction was accompanied by the formation of copious amounts of molecular iodine. Evidently, reductive dechlorination occurred at the expense of displacement, possibly due to steric interference by the ortho carboxyl group. The overall reaction is shown in Fig. 1.

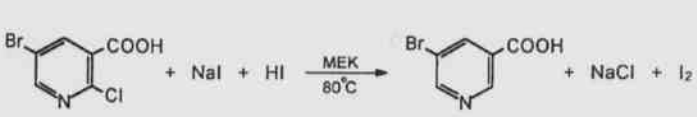

Fig. 1. Reductive dechlorination of 5-bromo-2-chloronicotinic acid.

Although iodide-induced reductive dechlorinations of several 4-chloro-2-pyridinecarboxylic acids (4-chloropicolinic acids) have been reported (Graf, H., J. Prakt. Chem. 148:13-19, 1937), high concentrations of hydroiodic acid together with red phosphorus and extremely elevated temperatures were required. To our knowledge, this note represents the first example of a reductive dechlorination of a 3-pyridinecarboxylic acid (nicotinic acid) and more significantly, under such mild conditions.

No exact mechanism for reactions of this type is described in the literature, but the process could involve initial iodide attack on chlorine of the N-protonated substrate yielding iodine monochloride and a 2-pyridyl anion, which could subsequently undergo protonation to afford the reduction product. Further reaction of iodine monochloride with iodide ion could then produce molecular iodine, which we observed.

The experiment was conducted as follows. A mixture of 5-bromo-2-chloronicotinic acid (Setliff, F., J. Chem. Eng. Data 590-591, 1970), (0.9 g, 0.0038 mole), sodium iodide (2.0 g, 0.013 mole), 57% hydroiodic acid (2 ml), water (1 mL), and methyl ethyl ketone (25 mL) was stirred under reflux for 48 hr. The reaction mixture was cooled to room temperature, and the sodium chloride which had precipitated (0.16 g, 72% of the theoretical) was removed by suction filtration. The reddish-brown filtrate was evaporated leaving a dark brown solid, which was washed with 10 mL of 10% sodium bisulfite to remove the iodine. The resulting light yellow powder was recrystallized from water, yielding light tan leaflets of 5-bromonicotinic acid (0.25 g, 32%), mp 180-182° C. The infrared spectrum was superimposable on that of an authentic sample obtained from Aldrich Chemical Co., Milwaukee, WI. A mixture melting point with an authentic sample showed no depression. The 200 MHz proton NMR spectrum in DMSO-d_6 with tetramethylsilane as the internal standard showed three aromatic protons: δ 9.04 (H-2), 8.96 (H-6), and 8.42 (H-4) ppm, all singlets in the area ratio of 1:1:1. The carboxyl proton appeared in the water signal at 3.42 ppm as a result of exchange with the water present in the DMSO.

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Swimming Behavior in the Fox Squirrel, *Sciurus niger* (Rodentia: Sciuridae), from Northeastern Arkansas

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Although both gray squirrels (*Sciurus carolinensis*) and fox squirrels (*S. niger*) are known to be excellent swimmers (e.g., see Mumford and Whitaker, 1982; Hoffmeister, 1989), references to swimming behavior in these squirrels have appeared infrequently in the literature (see Koprowski, 1994). The first published incidence in S. *niger* occurred in Illinois (Applegate and McCord, 1974); since then, no recent information on swimming in *S. niger* is available in state and regional mammalogy textbooks from areas west of the Mississippi River (e.g., Arkansas--Sealander and Heidt, 1990; Colorado--Fitzgerald et al., 1994; Missouri--Schwartz and Schwartz, 1981; Oklahoma--Caire et al., 1989; Choate et al., 1994; Jones et al., 1988; and others). Herein, we report on the first incidence of swimming behavior in *S. niger* from Arkansas.

While running turtle nets on 13 October 1996 at 11 40 hrs., we witnessed an adult *S. niger rufiventer* swimming northward across a 120 m span of the White River in Independence County at a point approximately 7.5 air km SE of Batesville. The sky was clear, and the air temperature was 23.0° C. The White River above Batesville is fed by two hydroelectric dams which contribute to a relatively cool water temperature which, on this day, was 14.4° C . A moderately swift current is present within this section of the river (at the confluence point with Salado Creek); the habitat is characterized by narrow bands of mostly bottomland hardwood forest on either side of the river. We encountered the squirrel at a point approximately three-fourths of the way across the river; although we circled the squirrel twice in an attempt to dissuade its progress, the squirrel continued toward the northern shoreline, stopped momentarily on a log, and then quickly disappeared into the vegetated underbrush. The squirrel's swimming technique (dog-paddling with its head, dorsum, and tail partially out of the water) was comparable to the description summarized by Koprowski (1994). Judging by the water distance the squirrel traveled during our observation, our best estimate of the length of time for the squirrel to transverse the river was 10-15 minutes.

Most literature accounts indicate that fox squirrels can be found in a diversity of habitats which would include riparian, bottomland communities (Koprowski, 1994); consequently, swimming may be a common occurrence in this species. In addition, the fall months are considered a time of dispersal for *S. niger*; therefore, this unusual sighting may have been associated with the annual emigration of individuals from populated areas (also known as the "fall reshuffle") as described by Sealander and Heidt (1990). Interviews with local fishermen and fishing guides that frequent the White River suggest that squirrels are rarely seen swimming the river. When they are, it usually involves large groups of gray squirrels migrating during the fall months, with fox squirrels being observed less frequently. One such event was described by Jack Hinkle, who has owned a fishing guide service on the White River near Sylamore, Arkansas (Izard County) since 1961. Mr. Hinkle reports witnessing hundreds of gray and fox squirrels (usually in groups of three or four) swimming across the river in October, 1991. All of the squirrels were going from north to south and the swimming behavior lasted for two or three days. This is the only time he can remember seeing squirrels swimming the river even though he has owned the guide service there for more than 35 years. Likewise, Charles Kibbee, a prominent bass fisherman from Batesville, Arkansas reports witnessing a similar migration of squirrels in the fall of 1991. While fishing in a bass tournament on Bull Shoals Lake, a reservoir on the White River system, Mr. Kibbee saw several squirrels swimming across the reservoir over a two-day period. They were all swimming in the same direction and several drowned. He reported seeing gray squirrels primarily, but also observed fox squirrels in lesser numbers.

We also spoke with Arkansas Game and Fish Commission biologists Fred Ward (small-game biologist) and Keith Sutton (editor of *Arkansas Wildlife Magazine*), and they described similar occurrences being reported by the public on other rivers and lakes in the state but could provide no documentation.

We thank V. R. McDaniel for reading the manuscript and J. L. Koprowski for his insightful comments regarding squirrel behavior. The Arkansas Game and Fish Commission provided financial support for the field research.

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CORRECTION - In the article "Subspecific Recognition in Arkansas Ringsneck Snakes *(Diadophis punctatus)*" by Stanley E. Trauth which appeared in Volume 50 of the Proceedings of the Arkansas Academy of Science, Page 145 and in the Table of Contents ". . .Arkansas Ringsneck Snakes" should read ". . .Arkansas Ringneck Snakes".

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Each submitted paper should contain results of original research, embody sound principles of scientific investigation, and present data in a concise yet clear manner. The COUNCIL OF BIOLOGY EDITORS STYLE MANUAL, published by the American Institute of Biological Sciences, is an example of a convenient and widely consulted guide for scientific writers. Authors should strive for directness and lucidity, achieved by use of the active voice. Special attention should be given to consistency in tense, unambiguous reference of pronouns, and to logically placed modifiers. It is strongly recommended that all authors 1) inspect the existing format for feature articles and general notes in the JOURNAL OF THE ARKANSAS ACADEMY OF SCIENCE and follow that format while drafting their submission, and 2) submit their manuscript to another qualified person for a friendly review to appraise it for clarity, brevity, grammar, and typographical errors.

Preparation of Manuscript

The author should submit three copies of the manuscript, tables, and figures. Manuscripts must be double spaced (preferably typed with a carbon ribboned typewriter) on 81/2 x 11 inch bond paper with at least one inch margins on all sides. Do not staple pages together. Do not hyphenate words on the right-hand margin; do not submit word processed copy printed with justified right-hand margins. Do not submit copy in italics; underline words to be set in italics. If co-authored, designate which author is to receive correspondence and at what address.

An abstract summarizing in concrete terms the methods, findings and implications discussed in the body of the paper must accompany a feature article. The abstract should be completely self-explanatory.

A feature article comprises approximately six or more typewritten pages. A JOURNAL printed page is equal to approximately three and one-half typewritten pages and the author is assessed a PAGE CHARGE (see Procedure section). A separate title page, including authors names and addresses should be included with the manuscript. Feature articles are often divided into the following sections: abstract, introduction, materials and methods, results, discussion, conclusions, acknowledgments, and literature cited. These sections should be centered. Subheadings should begin at the left -hand margin, but more than one subheading should be avoided.

A general note is usually one to five typewritten pages and rarely utilizes subheadings. A note should have the title at the top of the first page with the body of the paper following. Abstracts are not used for general notes.

Abbreviations: Use of abbreviations and symbols can be ascertained by inspection of recent issues of the JOURNAL. Suggestions for uniformity include the use of numerals before units of measurements (5 m), but nine animals (10 or numbers above, such as 13 animals). Abbreviations must be defined the first time they are used. The metric system of measurements and weights must be employed.

The literature cited section for feature articles should include six or more references; entries should take the following form:

Davis, D. H. S. 1993. Rhythmic activity in the short-tailed vole, *Microtus*. J. Anim. Ecol. 2:232-238.

Hudson, J. W. and **J. A. Rummell.** 1966

Fleming, T. H. 1969. Population ecology of three species of neotropical rodents. Unpublished Ph.D. dissertation. Univ. Michigan, Ann Arbor. 231 pp.

Jones, I. C. 1957. The adrenal cortex. Cambridge Univ. Press, London, 316 pp.

Wright, P. L.1966. Observations on the reproductive cycle of the American badger (*Taxides taxus*). Pp. 27-45, *In* Comparative biology of reproduction in mammals (I. W. Rowlands, ed.) Academic Press, London. xxi + 559 pp.

If fewer than six references are cited in a general note, they should be inserted in text and take these forms: (Jones, The adrenal cortex, Cambridge Univ. Press. p. 210, 1957); (Davis, J. Anim. Ecol., 2:232-238, 1933).

Tables and Illustrations: Tables and figures (line drawings, graphs, or black and white photographs) should not repeat data contained in the text. The author must provide numbers and short legends for illustrations and tables and place reference to each of them in the text. Legends for figures should be typed on a separate piece of paper at the end of the manuscript. Do not run tables in the text. **frustrations must be of sufficient size and clarity to permit reduction to standard page size (or 1/2 page); ordinarily** they should be no larger then twice the size of intended reduction and whenever possible no larger than a manuscript page for ease of handling. Photographs must be printed on glossy paper. Sharp focus and high contrast are essential for good reproduction. Figures and labeling must be of professional quality. Notations identifying author, figure number, and top of print must be made on the back of each illustration. All illustrations must be submitted in duplicate. Tables must be of professional quality when submitted. Note preferred placement of figures and tables in the margins of the manuscript.

Review Procedure

Evaluation of a paper submitted to the JOURNAL begins with a critical reading by the Editor. The paper is then submitted to referees for checking of scientific content, originality, and clarity of presentation. Attention to the proceeding paragraphs will greatly speed up this process. Judgments as to the acceptability of the paper and suggestions for strengthening it are sent to the author. If the paper is tentatively accepted, the author will rework it, where necessary, and return two copies of the revised manuscript together with the original to the Editor. Usually a time limit for this revision will be requested. If the time limit is not met, the paper may be considered to be withdrawn by the author and rejected for publication. All final decisions concerning the acceptance or rejection of a manuscript are made by the Editor.

When a copy of the proof, original manuscript, and reprint order blanks reach the author, they should be carefully read for errors and omissions. The author should mark corrections on the proof and return both the proof and manuscript to the Editor within 48 hours or the proof will be judged correct. Printing charges accruing from excessive additions to or changes in the proofs must be assumed by the author. Reprint charges are placed with the printer, not the Editor. Page changes are $40 printed page. These changes and excessive printing charges will be billed to the author by the Academy of Science. A page charge will be billed to the author of errata.

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